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CONTENTS

Volume 53, No. 1, March 2016 **Page**

Research Articles

Obituaries

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Research Article

Some Properties of Certain New Subclasses of Analytic Functions

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Abstract: In this paper, we introduce some new subclasses of analytic functions related to starlike, convex, close-to-convex and quasi-convex functions defined by using a generalized operator. Inclusion relationships for these subclasses are established. Also, we introduce some integral-preserving properties. Moreover, connections of the results presented here with those obtained in earlier works are pointed out.

Keywords: Analytic function, starlike function, convex function, close-to-convex, quasi-convex,
2010 MSC: 30C45

1. INTRODUCTION

Let $\mathbf{A}$ denotes the class of functions $f(z)$ which are analytic in $U=\{z\in\mathbb{C}:|z|<1\}$ and be given by

$$f(z)=z+\sum_{n=2}^{\infty}a_n z^n. \tag{1}$$

Let S denotes the subclass of $\mathbf{A}$ consisting of univalent functions in U. A function $f(z)\in S$ is called starlike function of order $\alpha(0\le\alpha<1)$ if and only if

$$Re\left\{\frac{zf'(z)}{f(z)}\right\}>\alpha\left(0\le\alpha<1;z\in U\right), \tag{2}$$

we denote the class of starlike functions by $S^*(\alpha)$. Also, a function $f(z)\in S$ is called convex function of order $\alpha(0\le\alpha<1)$ if and only if

$$Re\left\{1+\frac{zf''(z)}{f'(z)}\right\}>\alpha\left(0\le\alpha<1;z\in U\right). \tag{3}$$

We denote this class by $C(\alpha)$. It is well known that:

$$f(z)\in C(\alpha)\Leftrightarrow zf'(z)\in S^*(\alpha)\left(0\le\alpha<1;z\in U\right). \tag{4}$$

A function $f(z)\in\mathbf{A}$ is called close-to-convex function of order $\beta(0\le\beta<1)$ and type $\alpha(0\le\alpha<1)$, if there exist a function $g(z)\in S^*(\alpha)$ such that

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$$Re\left\{\frac{zf'(z)}{g(z)}\right\}>\beta\left(0\le\beta<1;z\in U\right), \tag{5}$$

we denote this class by $K(\beta,\alpha)$. Also, a function $f(z)\in\mathbf{A}$ is called quasi-convex function of order $\beta(0\le\beta<1)$ and type $\alpha(0\le\alpha<1)$, if there exists a function $g(z)\in C(\alpha)$ such that

$$Re\left\{\frac{\left(zf'(z)\right)'}{g'(z)}\right\}>\beta\left(0\le\beta<1;z\in U\right), \tag{6}$$

we denote this class by $K^{*}(\beta,\alpha)$. Similarly, It is well known that:

$$f(z)\in K^{*}(\beta,\alpha)\Leftrightarrow zf'(z)\in K(\beta,\alpha)\ \left(0\le\alpha,\beta<1;z\in U\right). \tag{7}$$

For further information about starlike, convex, close-to-convex and quasi-convex function, see [18], [23], [25], [27], [31], [33], [36] and [37] etc.

Following the recent work of El-Ashwah and Aouf [11] and [10, with $p=1$], for $m\in\mathbb{N}_0=\{0,1,2,...\}$, $\lambda>0$, $l>-1$ and $f(z)\in\mathbf{A}$ given by (1), the integral operator $L^{m}_{\lambda,l}$ is defined as follows:

$$L^{m}_{\lambda,l}f(z)=\begin{cases}f(z), & m=0,\\ \frac{l+1}{\lambda}z^{1-\frac{l+1}{\lambda}}\int_0^z t^{\frac{l+1}{\lambda}-2}L^{m-1}_{\lambda,l}f(t)dt, & m=1,2,\dots.\end{cases} \tag{8}$$

It is clear from (8) that:

$$L^{m}_{\lambda,l}f(z)=z+\sum_{n=2}^{\infty}\left(\frac{l+1}{l+\lambda(n-1)+1}\right)^{m}a_n z^n\ (\lambda>0;l>-1;m\in\mathbb{N}_0). \tag{9}$$

Also, for $A>0$ and $a,c\in\mathbb{C}$, are such that $Re\{c-a\}\ge 0$, Raina and Sharma [32] defined the integral operator $J^{a,c}_{A}:\ \mathbf{A}\to\mathbf{A}$, as follows:

(i) for $Re\{c-a\}>0$ and $Re\{a\}>-A$ by

$$J^{a,c}_{A}f(z)=\frac{\Gamma(c+A)}{\Gamma(a+A)}\frac{1}{\Gamma(c-a)}\int_0^1(1-t)^{c-a-1}t^{a-1}f(zt^{A})dt; \tag{10}$$

(ii) for $a=c$ by

$$J^{a,a}_{A}f(z)=f(z). \tag{11}$$

For $f(z)$ defined by (1), it is easily from (10) and (11) that:

$$J^{a,c}_{A}f(z)=z+\frac{\Gamma(c+A)}{\Gamma(a+A)}\sum_{n=2}^{\infty}\frac{\Gamma(a+nA)}{\Gamma(c+nA)}a_n z^n. \tag{12}$$

$$(A>0;a,c\in\mathbb{C};Re\{c-a\}\ge 0;Re\{a\}>-A)$$

By combining the two linear operators $L^{m}_{\lambda,l}$ and $J^{a,c}_{A}$. Then, the generalized operator

$$I^{m}_{\lambda,l}(a,c,A):\ \mathbf{A}\to\mathbf{A},$$

is defined for the purpose of this paper as follows:

$$I^{m}_{\lambda,l}(a,c,A)f(z)=L^{m}_{\lambda,l}\left(J^{a,c}_{A}f(z)\right)=J^{a,c}_{A}\left(L^{m}_{\lambda,l}f(z)\right), \tag{13}$$

which can be easily expressed as follows:

$$I_{\lambda,l}^{m}(a,c,A)f(z)=z+\frac{\Gamma(c+A)}{\Gamma(a+A)}\sum_{n=2}^{\infty}\frac{\Gamma(a+nA)}{\Gamma(c+nA)}\left(\frac{l+1}{l+\lambda(n-1)+1}\right)^{m}a_n z^n, \tag{14}$$

$$(A>0;a,c\in\mathbb{C};Re\{c-a\}\geq 0;Re\{a\}>-A;\lambda>0;l>-1;m\in\mathbb{N}_0).$$

In view of (1.8), (1.11) and (1.13), it is clear that:

$$I_{\lambda,l}^{0}(a,c,A)f(z)=J_A^{a,c}f(z) \quad \text{and} \quad I_{\lambda,l}^{m}(a,a,A)f(z)=L_{\lambda,l}^{m}f(z). \tag{15}$$

By specializing the parameters in (1.14), we note that the operator $I_{\lambda,l}^{m}(a,c,A)$ generalizes a lot of previous operators, as follows:

(i) $I_{\lambda,l}^{m}(\mu-1,0,1)f(z)=I_{\lambda,l,\mu}^{m}f(z)\left(\lambda>0;l>-1;\mu>0;m\in\mathbb{N}_0=\{0,1,2,...\}\right)$ (see Aouf and El-Ashwah [3]);

(ii) $I_{1,l}^{s}(\mu-1,0,1)f(z)=I_{l,\mu}^{s}f(z)\left(l>-1;\mu>0;s\in\mathbb{R}\right)$ (see Cho and Kim [8]);

(iii) $I_{\lambda,0}^{m}(\mu-1,0,1)f(z)=I_{\lambda,\mu}^{m}f(z)\left(\lambda>0;\mu>0;m\in\mathbb{Z}\right)$ (see Aouf et al. [2]);

(iv) $I_{\lambda,l}^{-n}(a,a,A)f(z)=I^{n}(\lambda,l)f(z)\left(\lambda>0;l>-1;n\in\mathbb{N}_0\right)$ (see Catas [7]);

(v) $I_{\lambda,l}^{m}(a,a,A)f(z)=J^{m}(\lambda,l)f(z)\left(\lambda>0;l>-1;m\in\mathbb{N}_0\right)$ (see El-Ashwah and Aouf [10]);

(vi) $I_{\lambda,0}^{-n}(a,a,A)f(z)=I_{\lambda}^{n}f(z)\left(\lambda>0;n\in\mathbb{Z}\right)$ (see Patel [30]);

(vii) $I_{1,\alpha-1}^{\mu}(a,a,A)f(z)=L_{\alpha}^{\mu}f(z)\left(\mu>0;\alpha>0\right)$ (see Komatu [16]; Aouf [1]);

(viii) $I_{1,1}^{\sigma}(a,a,A)f(z)=L^{\sigma}f(z)\left(\sigma>0\right)$ (see Jung et al. [15]; Liu [19]);

(ix) $I_{1,1}^{\beta}(a,a,A)f(z)=L^{\beta}f(z)\left(\beta\in\mathbb{Z}\right)$ (see Uralegaddi and Somanatha [39]; Flett [12]);

(x) $I_{1,0}^{n}(a,a,A)f(z)=I^{n}f(z)\left(n\in\mathbb{N}_0\right)$ and $I_{1,0}^{-n}(a,a,A)f(z)=D^{n}f(z)\left(n\in\mathbb{N}_0\right)$ (see Salagean [35]);

(xi) $I_{1,l}^{\mu}(a,a,A)f(z)=P_l^{\mu}f(z)\left(\mu>0;l>-1\right)$ (see Gao et al. [13]);

(xii) $I_{1,\sigma}^{1}(a,a,A)f(z)=L_{\sigma}f(z)\left(\sigma>0\right)$ (see Owa and Srivastava [29]; Srivastava and Owa [38]);

(xiii) $I_{\lambda,l}^{0}(\beta,\alpha+\beta-\gamma+1,1)f(z)=\Re_{\beta}^{\alpha,\gamma}f(z)\left(\gamma>0;\alpha\geq\gamma-1;\beta>-1\right)$ (see Aouf et al. [4]);

(xiv) $I_{\lambda,l}^{0}(\beta,\alpha+\beta,1)f(z)=Q_{\beta}^{\alpha}f(z)\left(\alpha\geq 0;\beta>-1\right)$ (see Liu and Owa [21]; Jung et al. [15]; Li [17]; Liu [20]);

(xv) $I_{\lambda,l}^{0}(a-1,c-1,1)f(z)=L(a,c)f(z)\left(a,c\in\mathbb{C}\setminus\mathbb{Z}_0^{-},\mathbb{Z}_0^{-}=\{0,-1,-2,...\}\right)$ (see Carlson and Shaffer [6]);

(xvi) $I_{\lambda,l}^{0}(\mu-1,\nu,1)f(z)=I_{\nu,\mu}f(z)\left(\mu>0;\nu>-1\right)$ (see Choi et al. [9]);

(xvii) $I_{\lambda,l}^{0}(\alpha,0,1)f(z)=D^{\alpha}f(z)\left(\alpha>-1\right)$ (see Ruscheweyh [34]);

(xviii) $I_{\lambda,l}^{0}(1,n,1)f(z)=D^{n}f(z)\left(n\in\mathbb{N}_0\right)$ (see Noor [26]; Noor and Noor [28]).

Using (1.14), we can obtain the following recurrence relations, which are needed for our proofs in following two sections:

$$z\left(I_{\lambda,l}^{m+1}(a,c,A)f(z)\right)'=\frac{1+l}{\lambda}I_{\lambda,l}^{m}(a,c,A)f(z)-\frac{1+l-\lambda}{\lambda}I_{\lambda,l}^{m+1}(a,c,A)f(z), \tag{16}$$

$$z\left(I_{\lambda,l}^{m}(a,c,A)f(z)\right)' = \frac{a+A}{A} I_{\lambda,l}^{m}(a+1,c,A)f(z) - \frac{a}{A} I_{\lambda,l}^{m}(a,c,A)f(z). \tag{17}$$

Definition 1. By using the operator $I_{\lambda,l}^{m}(a,c,A)f(z)$ defined by (14), we introduce the following subclasses of the class $\mathbf{A}$, as follows:

$$S_{\lambda,l}^{*m}(a,c,A;\alpha) = \left\{f : f(z) \in \mathbf{A} \text{ and } I_{\lambda,l}^{m}(a,c,A)f(z) \in S^{*}(\alpha)\right\}, \tag{18}$$

$$C_{\lambda,l}^{m}(a,c,A;\alpha) = \left\{f : f(z) \in \mathbf{A} \text{ and } I_{\lambda,l}^{m}(a,c,A)f(z) \in C(\alpha)\right\}, \tag{19}$$

$$K_{\lambda,l}^{m}(a,c,A;\beta,\alpha) = \left\{f : f(z) \in \mathbf{A} \text{ and } I_{\lambda,l}^{m}(a,c,A)f(z) \in K(\beta,\alpha)\right\}, \tag{20}$$

$$K_{\lambda,l}^{*m}(a,c,A;\beta,\alpha) = \left\{f : f(z) \in \mathbf{A} \text{ and } I_{\lambda,l}^{m}(a,c,A)f(z) \in K^{*}(\beta,\alpha)\right\}, \tag{21}$$

$$(A > 0, a,c \in \mathbb{C}, Re\{c-a\} \geq 0, Re\{a\} > -A, \lambda > 0, l > -1, 0 \leq \alpha, \beta < 1, m \in \mathbb{N}_0).$$

Remark 1. If we set $a = c$ in Definition 1, we obtain the following subclasses of $\mathbf{A}$:

$$S_{\lambda,l}^{*m}(\alpha) = \left\{f : f(z) \in \mathbf{A} \text{ and } L_{\lambda,l}^{m} f(z) \in S^{*}(\alpha)\right\}, \tag{22}$$

$$C_{\lambda,l}^{m}(\alpha) = \left\{f : f(z) \in \mathbf{A} \text{ and } L_{\lambda,l}^{m} f(z) \in C(\alpha)\right\}, \tag{23}$$

$$K_{\lambda,l}^{m}(\beta,\alpha) = \left\{f : f(z) \in \mathbf{A} \text{ and } L_{\lambda,l}^{m} f(z) \in K(\beta,\alpha)\right\}, \tag{24}$$

$$K_{\lambda,l}^{*m}(\beta,\alpha) = \left\{f : f(z) \in \mathbf{A} \text{ and } L_{\lambda,l}^{m} f(z) \in K^{*}(\beta,\alpha)\right\}. \tag{25}$$

Where $L_{\lambda,l}^{m} f(z)$ is defined by (9).

Remark 2. If we set $m = 0$ in Definition 1, we obtain the following subclasses of $\mathbf{A}$:

$$S^{*}(a,c,A;\alpha) = \left\{f : f(z) \in \mathbf{A} \text{ and } J_{A}^{a,c} f(z) \in S^{*}(\alpha)\right\}, \tag{26}$$

$$C(a,c,A;\alpha) = \left\{f : f(z) \in \mathbf{A} \text{ and } J_{A}^{a,c} f(z) \in C(\alpha)\right\}, \tag{27}$$

$$K(a,c,A;\beta,\alpha) = \left\{f : f(z) \in \mathbf{A} \text{ and } J_{A}^{a,c} f(z) \in K(\beta,\alpha)\right\}, \tag{28}$$

$$K^{*}(a,c,A;\beta,\alpha) = \left\{f : f(z) \in \mathbf{A} \text{ and } J_{A}^{a,c} f(z) \in K^{*}(\beta,\alpha)\right\}. \tag{29}$$

Where $J_{A}^{a,c} f(z)$ is defined by (12).

In order to introduce our main results, we shall need the following lemma which is given by Miller and Mocanu [24].

Lemma 1. *Let $u = u_1 + iu_2$, $v = v_1 + iv_2$ and let $\psi(u,v)$ be a complex-valued function such that*

$$\psi : D \to \mathbb{C} \quad (D \subset \mathbb{C} \times \mathbb{C}).$$

Suppose also that the function $\psi(u,v)$ satisfies each of the following conditions:

(i) $\psi(u,v)$ *is continuous in* D;

(ii) $(1,0) \in D$ *and* $Re\{\psi(1,0)\} > 0$;

(iii) $Re\{\psi(iu_2, v_1)\} \leq 0$ *for all* $(iu_2, v_1) \in D$ *such that*

$$v_1 \leq -\frac{1}{2}(1+u_2^2). \tag{30}$$

Let

$$h(z)=1+c_1z+c_2z^2+\ldots, \tag{31}$$

be analytic in U *such that* $(h(z),zh'(z))\in D$ $(z\in U)$. *If* $Re\{\psi(h(z),zh'(z))\}>0$ $(z\in U)$, *then* $Re\{h(z)\}>0$ *for* $z\in U$.

2. INCLUSION RELATIONSHIPS

Unless otherwise mentioned, we shall assume throughout the paper that $A>0$, $a,c\in\mathbb{C}$, $Re\{c-a\}\geq 0$, $Re\{a\}>-A$, $\lambda>0$, $l>-1$, $0\leq\alpha,\beta<1$, $m\in\mathbb{N}_0$ and $f(z)\in\mathbf{A}$.

In this section, we give several inclusion relationships for analytic function classes, which are associated with the generalized operator $I^m_{\lambda,l}(a,c,A)f(z)$ defined by (14).

Theorem 1. *Let* $a=a_1+ia_2$ with $Re\{a\}>-A\alpha$, *then*

$$S^{*m}_{\lambda,l}(a+1,c,A;\alpha)\subset S^{*m}_{\lambda,l}(a,c,A;\alpha)\subset S^{*m+1}_{\lambda,l}(a,c,A;\alpha). \tag{32}$$

Proof**.** (i) we begin with showing the first inclusion relationship

$$S^{*m}_{\lambda,l}(a+1,c,A;\alpha)\subset S^{*m}_{\lambda,l}(a,c,A;\alpha), \tag{33}$$

which is asserted by Theorem 1. Let $f(z)\in S^{*m}_{\lambda,l}(a+1,c,A;\alpha)$ and set

$$\frac{z\left(I^m_{\lambda,l}(a,c,A)f(z)\right)'}{I^m_{\lambda,l}(a,c,A)f(z)}-\alpha=(1-\alpha)h(z), \tag{34}$$

where $h(z)$ is defined by (31). By using the identity (17) and (34), we obtain

$$\frac{a+A}{A}\frac{I^m_{\lambda,l}(a+1,c,A)f(z)}{I^m_{\lambda,l}(a,c,A)f(z)}=(1-\alpha)h(z)+\alpha+\frac{A}{a}. \tag{35}$$

By using logarithmic differentiation on both sides of (35), we obtain

$$\frac{z\left(I^m_{\lambda,l}(a+1,c,A)f(z)\right)'}{I^m_{\lambda,l}(a+1,c,A)f(z)}=\frac{z\left(I^m_{\lambda,l}(a,c,A)f(z)\right)'}{I^m_{\lambda,l}(a,c,A)f(z)}+\frac{(1-\alpha)zh'(z)}{(1-\alpha)h(z)+\alpha+\frac{a}{A}},$$

using (34) in the above equation, we obtain

$$\frac{z\left(I^m_{\lambda,l}(a+1,c,A)f(z)\right)'}{I^m_{\lambda,l}(a+1,c,A)f(z)}-\alpha=(1-\alpha)h(z)+\frac{(1-\alpha)zh'(z)}{(1-\alpha)h(z)+\alpha+\frac{a}{A}}.$$

or

$$\frac{z\left(I^m_{\lambda,l}(a+1,c,A)f(z)\right)'}{I^m_{\lambda,l}(a+1,c,A)f(z)}-\alpha=(1-\alpha)h(z)+\frac{A(1-\alpha)zh'(z)}{A\left[(1-\alpha)h(z)+\alpha\right]+a}. \tag{36}$$

Now, we choose $u=h(z)=u_1+iu_2$ and $v=zh'(z)=v_1+iv_2$, and define the function $\psi(u,v)$ by

$$\psi(u,v)=(1-\alpha)u+\frac{A(1-\alpha)v}{A\left[(1-\alpha)u+\alpha\right]+a}.$$

It is easy to see that the function $\psi(u,v)$ satisfies conditions (i) and (ii) of Lemma 1 in $D=\left(\mathbb{C}\setminus\left\{\frac{\alpha A+a}{A(\alpha-1)}\right\}\right)\times\mathbb{C}$. Also, we verify condition (iii) as follows:

$$\operatorname{Re}\{\psi(iu_2,v_1)\}=\operatorname{Re}\left\{\frac{A(1-\alpha)v_1}{A\left[(1-\alpha)iu_2+\alpha\right]+a}\right\}=\frac{A(\alpha A+a_1)(1-\alpha)v_1}{\left[(A\alpha+a_1)^2+(A(1-\alpha)u_2+a_2)^2\right]}$$

$$\leq-\frac{A(\alpha A+a_1)(1-\alpha)(1+u_2^2)}{2\left[(A\alpha+a_1)^2+(A(1-\alpha)u_2+a_2)^2\right]}<0.$$

Which shows that $\psi(u,v)=\psi(h(z),zh'(z))$ $(z\in U)$ satisfies the hypotheses of the Lemma 1, then $Re\{h(z)\}>0$ $(z\in U)$, then using (34), we have $f(z)\in S_{\lambda,l}^{*m}(a,c,A;\alpha)$. This completes the proof of (33).

(ii) Now, we prove

$$S_{\lambda,l}^{*m}(a,c,A;\alpha)\subset S_{\lambda,l}^{*m+1}(a,c,A;\alpha), \tag{37}$$

which is the second inclusion relationship of Theorem 1. Let $f(z)\in S_{\lambda,l}^{*m}(a,c,A;\alpha)$ and set

$$\frac{z\left(I_{\lambda,l}^{m+1}(a,c,A)f(z)\right)'}{I_{\lambda,l}^{m+1}(a,c,A)f(z)}-\alpha=(1-\alpha)h(z), \tag{38}$$

where $h(z)$ is defined by (31). By applying the identity (16) in (38), we obtain

$$\frac{1+l}{\lambda}\frac{I_{\lambda,l}^{m}(a,c,A)f(z)}{I_{\lambda,l}^{m+1}(a,c,A)f(z)}=(1-\alpha)h(z)+\alpha+\frac{1+l-\lambda}{\lambda}. \tag{39}$$

By using logarithmic differentiation on both sides of (39), we obtain

$$\frac{z\left(I_{\lambda,l}^{m}(a,c,A)f(z)\right)'}{I_{\lambda,l}^{m}(a,c,A)f(z)}-\frac{z\left(I_{\lambda,l}^{m+1}(a,c,A)f(z)\right)'}{I_{\lambda,l}^{m+1}(a,c,A)f(z)}=\frac{(1-\alpha)zh'(z)}{(1-\alpha)h(z)+\alpha+\frac{1+l-\lambda}{\lambda}},$$

using (38) in the above equation, we have

$$\frac{z\left(I_{\lambda,l}^{m}(a,c,A)f(z)\right)'}{I_{\lambda,l}^{m}(a,c,A)f(z)}-\alpha=(1-\alpha)h(z)+\frac{\lambda(1-\alpha)zh'(z)}{\lambda\left((1-\alpha)h(z)+\alpha\right)+(1+l-\lambda)}. \tag{40}$$

By using arguments similar to those detailed before, together with (40) and $\psi(u,v)$ is continuous in $D=\left(\mathbb{C}\setminus\left\{1-\frac{l+1}{\lambda(1-\alpha)}\right\}\right)\times\mathbb{C}$, then we can prove (37), which is the second inclusion relationship of Theorem 1. Combining the inclusion relationships (33) and (37), we complete the proof of Theorem 1.

Theorem 2. *Let* $a=a_1+ia_2$ with $Re\{a\}>-A\alpha$, *then*

$$C_{\lambda,l}^{m}(a+1,c,A;\alpha)\subset C_{\lambda,l}^{m}(a,c,A;\alpha)\subset C_{\lambda,l}^{m+1}(a,c,A;\alpha). \tag{41}$$

Proof. We first show that

$$C_{\lambda,l}^{m}(a+1,c,A;\alpha)\subset C_{\lambda,l}^{m}(a,c,A;\alpha). \tag{42}$$

Let $f(z)\in C_{\lambda,l}^{m}(a+1,c,A;\alpha)$. Then, using Theorem 1, we have

$$
\begin{aligned}
I_{\lambda,l}^{m}(a+1,c,A)f(z)\in C(\alpha) \quad &\Leftrightarrow z\left(I_{\lambda,l}^{m}(a+1,c,A)f(z)\right)'\in S^{*}(\alpha)\\
&\Leftrightarrow I_{\lambda,l}^{m}(a+1,c,A)zf'(z)\in S^{*}(\alpha)\\
&\Leftrightarrow zf'(z)\in S_{\lambda,l}^{*m}(a+1,c,A;\alpha)\\
&\Rightarrow zf'(z)\in S_{\lambda,l}^{*m}(a,c,A;\alpha)\\
&\Leftrightarrow I_{\lambda,l}^{m}(a,c,A)zf'(z)\in S^{*}(\alpha)\\
&\Leftrightarrow z\left(I_{\lambda,l}^{m}(a,c,A)f(z)\right)'\in S^{*}(\alpha)\\
&\Leftrightarrow I_{\lambda,l}^{m}(a,c,A)f(z)\in C(\alpha)\\
&\Leftrightarrow f(z)\in C_{\lambda,l}^{m}(a,c,A;\alpha).
\end{aligned}
$$

This completes the proof of (42). By using arguments similar to those detailed above, we can also prove the right part of Theorem 2, that is, that

$$C_{\lambda,l}^{m}(a,c,A;\alpha)\subset C_{\lambda,l}^{m+1}(a,c,A;\alpha). \tag{43}$$

Combining the inclusion relationships (42) and (43), then the proof of Theorem 2 is completed.

Theorem 3. *Let* $a=a_1+ia_2$ with $Re\{a\}>-A\alpha$, *then*

$$K_{\lambda,l}^{m}(a+1,c,A;\beta,\alpha)\subset K_{\lambda,l}^{m}(a,c,A;\beta,\alpha)\subset K_{\lambda,l}^{m+1}(a,c,A;\beta,\alpha). \tag{44}$$

Proof. Let us begin with proving that

$$K_{\lambda,l}^{m}(a+1,c,A;\beta,\alpha)\subset K_{\lambda,l}^{m}(a,c,A;\beta,\alpha). \tag{45}$$

Let $f(z)\in K_{\lambda,l}^{m}(a+1,c,A;\beta,\alpha)$. Then there exists a function $g(z)\in S^{*}(\alpha)$ such that

$$Re\left\{\frac{z\left(I_{\lambda,l}^{m}(a+1,c,A)f(z)\right)'}{g(z)}\right\}>\beta\ \ (z\in U).$$

We put $g(z)=I_{\lambda,l}^{m}(a+1,c,A)k(z)$, so that we have $k(z)\in S_{\lambda,l}^{*m}(a+1,c,A;\alpha)$ and

$$Re\left\{\frac{z\left(I_{\lambda,l}^{m}(a+1,c,A)f(z)\right)'}{I_{\lambda,l}^{m}(a+1,c,A)k(z)}\right\}>\beta\ \ (z\in U).$$

Next, we put

$$\frac{z\left(I_{\lambda,l}^{m}(a,c,A)f(z)\right)'}{I_{\lambda,l}^{m}(a,c,A)k(z)}=(1-\beta)h(z)+\beta, \tag{46}$$

where $h(z)$ is given by (31). Thus, by using the identity (17), we obtain

$$
\begin{aligned}
\frac{z\left(I_{\lambda,l}^{m}(a+1,c,A)f(z)\right)'}{I_{\lambda,l}^{m}(a+1,c,A)k(z)} &= \frac{I_{\lambda,l}^{m}(a+1,c,A)zf'(z)}{I_{\lambda,l}^{m}(a+1,c,A)k(z)}\\
&= \frac{\frac{A}{A+a}z\left(I_{\lambda,l}^{m}(a,c,A)zf'(z)\right)'+\frac{a}{A+a}I_{\lambda,l}^{m}(a,c,A)zf'(z)}{\frac{A}{A+a}z\left(I_{\lambda,l}^{m}(a,c,A)k(z)\right)'+\frac{a}{A+a}I_{\lambda,l}^{m}(a,c,A)k(z)}\\
&= \frac{A\,\frac{z\left(I_{\lambda,l}^{m}(a,c,A)zf'(z)\right)'}{I_{\lambda,l}^{m}(a,c,A)k(z)}+a\,\frac{I_{\lambda,l}^{m}(a,c,A)zf'(z)}{I_{\lambda,l}^{m}(a,c,A)k(z)}}{A\,\frac{z\left(I_{\lambda,l}^{m}(a,c,A)k(z)\right)'}{I_{\lambda,l}^{m}(a,c,A)k(z)}+a}.
\end{aligned}
\tag{47}
$$

Since $k(z) \in S_{\lambda,l}^{*m}(a+1,c,A;\alpha)$, by using Theorem 1, we can put

$$\frac{z\left(I_{\lambda,l}^{m}(a,c,A)k(z)\right)'}{I_{\lambda,l}^{m}(a,c,A)k(z)} = (1-\alpha)G(z)+\alpha, \tag{48}$$

where $G(z) = g_1(x,y) + ig_2(x,y)$ and $Re\{G(z)\} = g_1(x,y) > 0$ $(z \in U)$. Using (46) and (48) in (47), we have

$$\frac{z\left(I_{\lambda,l}^{m}(a+1,c,A)f(z)\right)'}{I_{\lambda,l}^{m}(a+1,c,A)k(z)} = \frac{A\,\frac{z\left(I_{\lambda,l}^{m}(a,c,A)zf'(z)\right)'}{I_{\lambda,l}^{m}(a,c,A)k(z)} + a\left[\beta+(1-\beta)h(z)\right]}{A\left[(1-\alpha)G(z)+\alpha\right]+a}. \tag{49}$$

Moreover, from (46), we can put

$$z\left(I_{\lambda,l}^{m}(a,c,A)f(z)\right)' = \left[(1-\beta)h(z)+\beta\right]I_{\lambda,l}^{m}(a,c,A)k(z). \tag{50}$$

Differentiating both sides of (50) with respect to z, and using (46) and (48), we obtain

$$\frac{z\left(I_{\lambda,l}^{m}(a,c,A)zf'(z)\right)'}{I_{\lambda,l}^{m}(a,c,A)k(z)} = (1-\beta)zh'(z)+\left[(1-\beta)h(z)+\beta\right]\left[(1-\alpha)G(z)+\alpha\right]. \tag{51}$$

By substituting (51) into (49), we obtain

$$\frac{z\left(I_{\lambda,l}^{m}(a+1,c,A)f(z)\right)'}{I_{\lambda,l}^{m}(a+1,c,A)k(z)} - \beta = (1-\beta)h(z) + \frac{A(1-\beta)zh'(z)}{A\left[(1-\alpha)G(z)+\alpha\right]+a}. \tag{52}$$

In (52), take $u = h(z) = u_1 + iu_2$, $v = zh'(z) = v_1 + iv_2$ and define the function $\psi(u,v)$ by

$$\psi(u,v) = (1-\beta)u + \frac{A(1-\beta)v}{A\left[(1-\alpha)G(z)+\alpha\right]+a}, \tag{53}$$

where $(u,v) \in D = \mathbb{C}\times\mathbb{C}$. Then it follows from (53) that:

(i) $\psi(u,v)$ is continuous in D;

(ii) $(1,0) \in D$ and $Re\{\psi(1,0)\} = 1-\beta > 0$;

(iii) for all $(iu_2,v_1) \in D$ such that $v_1 \le -\frac{1}{2}\left(1+u_2^2\right)$, we have

$$\begin{aligned} Re\{\psi(iu_2,v_1)\} &= Re\left\{\frac{A(1-\beta)v_1}{A\left[(1-\alpha)G(z)+\alpha\right]+a}\right\} \\ &= \frac{\left(A(1-\beta)v_1\right)\left(A\left[(1-\alpha)g_1(z)+\alpha\right]+a_1\right)}{\left(A\left[(1-\alpha)g_1(z)+\alpha\right]+a_1\right)^2+\left(A(1-\alpha)g_2(z)+a_2\right)^2} \\ &= -\frac{\left(A(1-\beta)\left(1+u_2^2\right)\right)\left(A\left[(1-\alpha)g_1(z)+\alpha\right]+a_1\right)}{2\left[\left(A\left[(1-\alpha)g_1(z)+\alpha\right]+a_1\right)^2+\left(A(1-\alpha)g_2(z)+a_2\right)^2\right]} \\ &< 0, \end{aligned}$$

which shows that $\psi(u,v)$ satisfies the hypotheses of Lemma 1. Thus, in light of (46), we easily deduce the inclusion relationship (45).

The remainder of our proof of Theorem 3 would make use of the identity (16) in an analogous manner. Therefore, we choose to omit the details involved.

Theorem 4. *Let* $a = a_1 + ia_2$ with $Re\{a\} > -A\alpha$, *then*

$$K_{\lambda,l}^{*m}(a+1,c,A;\beta,\alpha) \subset K_{\lambda,l}^{*m}(a,c,A;\beta,\alpha) \subset K_{\lambda,l}^{*m+1}(a,c,A;\beta,\alpha). \tag{54}$$

Proof. Just, as we derived Theorem 2 as a consequence of Theorem 1 by using the equivalence (4). Similarly, we can prove Theorem 4 by using Theorem 3 in conjunction with the equivalence (7). Therefore, we choose to omit the details involved.

Remark 3.

(i) Taking $m = s\ (s \in \mathbb{R})$, $\lambda = 1$, $a = \mu - 1(\mu > 0)$, $c = 0$ and $A = 1$ in Theorems 1-3, we obtain the results obtained by Cho and Kim [8, Theorems 2.1-2.3 with $\varphi(z) = \psi(z) = \frac{1+z}{1-z}$];

(ii) Taking $a = \mu - 1(\mu > 0)$, $c = 0$ and $A = 1$ in Theorems 1-3, we obtain the results obtained by Aouf and El-Ashwah [3, Theorems 1-3 with $\varphi(z) = \psi(z) = \frac{1+z}{1-z}$];

(iii) Taking $l = 0$, $a = \mu - 1(\mu > 0)$, $c = 0$ and $A = 1$ in Theorems 1-3, we obtain the results obtained by Aouf et al. [2, Theorems 1-3 with $\varphi(z) = \psi(z) = \frac{1+z}{1-z}$].

Taking $a = c$ in Theorems 1-4, we obtain the following corollary.

Corollary 1. For the subclasses $S_{\lambda,l}^{*m}(\alpha)$, $C_{\lambda,l}^{m}(\alpha)$, $K_{\lambda,l}^{m}(\beta,\alpha)$ and $K_{\lambda,l}^{*m}(\beta,\alpha)$ defined in Remark 1, we have the following inclusion relations.

$$S_{\lambda,l}^{*m}(\alpha) \subset S_{\lambda,l}^{*m+1}(\alpha),$$

$$C_{\lambda,l}^{m}(\alpha) \subset C_{\lambda,l}^{m+1}(\alpha),$$

$$K_{\lambda,l}^{m}(\beta,\alpha) \subset K_{\lambda,l}^{m+1}(\beta,\alpha),$$

$$K_{\lambda,l}^{*m}(\beta,\alpha) \subset K_{\lambda,l}^{*m+1}(\beta,\alpha).$$

Remark 4.

(i) Taking $\lambda = 1$, $m = \mu(\mu > 0)$ and $l = a - 1(a > 0)$ in Corollary 1, we obtain the results obtained by Aouf [1, Theorems 1-4];

(ii) Taking $\lambda = l = 1$ and $m = \sigma(\sigma > 0)$ in Corollary 1, we obtain the results obtained by Liu [19, Theorems 1-4].

Taking $m = 0$ in Theorems 1-4, we obtain the following corollary.

Corollary 2. For the subclasses $S^*(a,c,A;\alpha)$, $C(a,c,A;\alpha)$, $K(a,c,A;\beta,\alpha)$ and $K^*(a,c,A;\beta,\alpha)$ defined in Remark 2, we have the following inclusion relations.

$$S^*(a+1,c,A;\alpha) \subset S^*(a,c,A;\alpha),$$

$$C(a+1,c,A;\alpha) \subset C(a,c,A;\alpha),$$

$$K(a+1,c,A;\beta,\alpha) \subset K(a,c,A;\beta,\alpha),$$

$$K^*(a+1,c,A;\beta,\alpha) \subset K^*(a,c,A;\beta,\alpha).$$

Remark 5. Taking $\alpha=\beta=0$, $a=\mu-1(\mu>0)$, $c=\lambda(\lambda>-1)$ and $A=1$ in the first three inclusion relationships of Corollary 2, we obtain the results obtained by Choi et al. [9, Theorems 1-3, only the first parts with $\varphi(z)=\psi(z)=\frac{1+z}{1-z}$].

3. INTEGRAL-PRESERVING PROPERTIES INVOLVING THE INTEGRAL OPERATOR L_σ

For $\sigma>-1$ and $f(z)\in\mathbf{A}$, we recall the generalized Bernardi-Libera-Livingston integral operator $L_\sigma : \mathbf{A}\to\mathbf{A}$, as following (see Owa and H. M. Srivastava [29]):

$$L_\sigma f(z)=\frac{\sigma+1}{z^{\sigma}}\int_0^z t^{\sigma-1}f(t)dt$$

$$=z+\sum_{n=2}^{\infty}\left(\frac{\sigma+1}{\sigma+n}\right)a_n z^n \quad (\sigma>-1, f(z)\in\mathbf{A}). \tag{55}$$

The operator $L_\sigma f(z)(\sigma\in\mathbb{N})$ was introduced by Bernardi [5]. In particular, the operator $L_1 f(z)$ was studied earlier by Libera [18] and Livingston [22]. Using (14) and (55), it is clear that $L_\sigma f(z)$ satisfies the following relationship:

$$z\left(I_{\lambda,l}^m(a,c,A)L_\sigma f(z)\right)'=(\sigma+1)I_{\lambda,l}^m(a,c,A)f(z)-\sigma I_{\lambda,l}^m(a,c,A)L_\sigma f(z). \tag{56}$$

In order to obtain the integral-preserving properties involving the integral operator L_σ, we need the following lemma which is known as Jack's Lemma (see [14]).

Lemma 2. [14]**.** *Let $\omega(z)$ be a non-constant function analytic in U with $\omega(0)=0$. If $|\omega(z)|$ attains its maximum value on the circle $|z|=r<1$ at z_0, then*

$$z_0\omega'(z_0)=\zeta\omega(z_0),$$

where ζ is a real number and $\zeta\geq 1$.

Theorem 5. *Let $\sigma>-\alpha$. If $f(z)\in S_{\lambda,l}^{*m}(a,c,A;\alpha)$, then*

$$L_\sigma f(z)\in S_{\lambda,l}^{*m}(a,c,A;\alpha).$$

Proof. Suppose that $f(z)\in S_{\lambda,l}^{*m}(a,c,A;\alpha)$ and let

$$\frac{z\left(I_{\lambda,l}^m(a,c,A)L_\sigma f(z)\right)'}{I_{\lambda,l}^m(a,c,A)L_\sigma f(z)}=\frac{1+(1-2\alpha)\omega(z)}{1-\omega(z)}, \tag{57}$$

where $\omega(0)=0$. Then, by using (56) and (57), we have

$$\frac{I_{\lambda,l}^m(a,c,A)f(z)}{I_{\lambda,l}^m(a,c,A)L_\sigma f(z)}=\frac{\sigma+1+(1-\sigma-2\alpha)\omega(z)}{(\sigma+1)(1-\omega(z))}, \tag{58}$$

which, upon logarithmic differentiation, yields

$$\frac{z\left(I_{\lambda,l}^m(a,c,A)f(z)\right)'}{I_{\lambda,l}^m(a,c,A)f(z)}=\frac{1+(1-2\alpha)\omega(z)}{1-\omega(z)}+\frac{z\omega'(z)}{1-\omega(z)}+\frac{(1-\sigma-2\alpha)z\omega'(z)}{(1-\sigma-2\alpha)\omega(z)+\sigma+1}, \tag{59}$$

so that

$$\frac{z\left(I_{\lambda,l}^{m}(a,c,A)f(z)\right)'}{I_{\lambda,l}^{m}(a,c,A)f(z)}-\alpha=(1-\alpha)\frac{1+\omega(z)}{1-\omega(z)}+\frac{z\,\omega'(z)}{1-\omega(z)}+\frac{(1-\sigma-2\alpha)z\,\omega'(z)}{(1-\sigma-2\alpha)\omega(z)+\sigma+1}. \quad (60)$$

Now, assuming that $\max_{|z|\le|z_0|}|\omega(z)|=|\omega(z_0)|=1\ (z\in U)$ and applying Jack's lemma, we obtain

$$z_0\omega'(z_0)=\zeta\omega(z_0)\ \ (\zeta\in\mathbb{R},\zeta\ge 1). \quad (61)$$

If we set $\omega(z_0)=e^{i\theta}\ (\theta\in\mathbb{R})$ in (60) and observe that

$$Re\left\{(1-\alpha)\frac{1+\omega(z_0)}{1-\omega(z_0)}\right\}=0,$$

then, we obtain

$$\begin{aligned}Re\left\{\frac{z\left(I_{\lambda,l}^{m}(a,c,A)f(z)\right)'}{I_{\lambda,l}^{m}(a,c,A)f(z)}-\alpha\right\}&=Re\left\{\frac{z_0\omega'(z_0)}{1-\omega(z_0)}+\frac{(1-\sigma-2\alpha)z_0\omega'(z_0)}{(1-\sigma-2\alpha)\omega(z_0)+\sigma+1}\right\}\\&=Re\left\{\frac{\zeta e^{i\theta}}{1-e^{i\theta}}+\frac{(1-\sigma-2\alpha)\zeta e^{i\theta}}{(1-\sigma-2\alpha)e^{i\theta}+\sigma+1}\right\}\\&=-\frac{2\zeta(\sigma+\alpha)(1-\alpha)}{2(1+\sigma)(1-\sigma-2\alpha)\cos\theta+(1+\sigma)^2+(1-\sigma-2\alpha)^2}\\&<0,\end{aligned}$$

which obviously contradicts the hypothesis $f(z)\in S_{\lambda,l}^{*m}(a,c,A;\alpha)$. Consequently, we can deduce that $|\omega(z)|<1\ (z\in U)$, which, in view of (57), proves the integral-preserving property asserted by Theorem 5.

Taking $a=c$ in Theorem 5, we obtain the following corollary.

Corollary 3. *Let* $\sigma>-\alpha$. *If* $f(z)\in S_{\lambda,l}^{*m}(\alpha)$, *then* $L_\sigma f(z)\in S_{\lambda,l}^{*m}(\alpha)$, where the subclass $S_{\lambda,l}^{*m}(\alpha)$ is defined by (22).

Remark 6.

(i) Taking $\lambda=1$, $m=\mu\ (\mu>0)$ and $l=a-1\ (a>0)$ in Corollary 3, we obtain the results obtained by Aouf [1, Theorem 5];

(ii) Taking $\lambda=l=1$ and $m=\sigma\ (\sigma>0)$ in Corollary 3, we obtain the results obtained by Liu [19, Theorem 5].

Taking $m=0$ in Theorem 5, we obtain the following corollary.

Corollary 4. *Let* $\sigma>-\alpha$. *If* $f(z)\in S^{*}(a,c,A;\alpha)$, *then* $L_\sigma f(z)\in S^{*}(a,c,A;\alpha)$, where the subclass $S^{*}(a,c,A;\alpha)$ is defined by (26).

Remark 7. Taking $\alpha=0$, $a=\mu-1\ (\mu>0)$, $c=\lambda\ (\lambda>-1)$ and $A=1$ in Corollary 4, we obtain the results obtained by Choi et al. [9, Theorem 4, with $\varphi(z)=\frac{1+z}{1-z}$].

Theorem 6. *Let* $\sigma > -\alpha$. *If* $f(z) \in C_{\lambda,l}^{m}(a,c,A;\alpha)$, *then*

$$L_{\sigma} f(z) \in C_{\lambda,l}^{m}(a,c,A;\alpha).$$

Proof. By applying Theorem 5, it follows that

$$\begin{aligned} f(z) \in C_{\lambda,l}^{m}(a,c,A;\alpha) &\Leftrightarrow zf'(z) \in S_{\lambda,l}^{*m}(a,c,A;\alpha) \\ &\Rightarrow L_{\sigma}\left(zf'(z)\right) \in S_{\lambda,l}^{*m}(a,c,A;\alpha) \\ &\Leftrightarrow z\left(L_{\sigma} f(z)\right)' \in S_{\lambda,l}^{*m}(a,c,A;\alpha) \\ &\Leftrightarrow L_{\sigma} f(z) \in C_{\lambda,l}^{m}(a,c,A;\alpha), \end{aligned}$$

which proves Theorem 6.

Taking $a = c$ in Theorem 6, we obtain the following corollary.

Corollary 5. *Let* $\sigma > -\alpha$. *If* $f(z) \in C_{\lambda,l}^{m}(\alpha)$, *then* $L_{\sigma} f(z) \in C_{\lambda,l}^{m}(\alpha)$, where the subclass $C_{\lambda,l}^{m}(\alpha)$ is defined by (23).

Remark 8.

(i) Taking $\lambda = 1$, $m = \mu(\mu > 0)$ and $l = a - 1(a > 0)$ in Corollary 5, we obtain the result obtained by Aouf [1, Theorem 6];

(ii) Taking $\lambda = l = 1$ and $m = \sigma(\sigma > 0)$ in Corollary 5, we obtain the result obtained by Liu [19, Theorem 6].

Taking $m = 0$ in Theorem 6, we obtain the following corollary.

Corollary 6. *Let* $\sigma > -\alpha$. *If* $f(z) \in C(a,c,A;\alpha)$, *then* $L_{\sigma} f(z) \in C(a,c,A;\alpha)$, where the subclass $C(a,c,A;\alpha)$ is defined by (27).

Remark 9. Taking $\alpha = 0$, $a = \mu - 1(\mu > 0)$, $c = \lambda(\lambda > -1)$ and $A = 1$ in Corollary 6, we obtain the results obtained by Choi et al.[9, Theorem 5, with $\varphi(z) = \frac{1+z}{1-z}$].

Theorem 7. *Let* $\sigma > -\alpha$. *If* $f(z) \in K_{\lambda,l}^{m}(a,c,A;\beta,\alpha)$, *then*

$$L_{\sigma} f(z) \in K_{\lambda,l}^{m}(a,c,A;\beta,\alpha).$$

Proof. Suppose that $f(z) \in K_{\lambda,l}^{m}(a,c,A;\beta,\alpha)$. Then, there exists a function $g(z) \in S_{\lambda,l}^{*m}(a,c,A;\alpha)$ such that

$$Re\left\{\frac{z\left(I_{\lambda,l}^{m}(a,c,A) f(z)\right)'}{I_{\lambda,l}^{m}(a,c,A) g(z)}\right\} > \beta.$$

Thus, upon setting

$$\frac{z\left(I_{\lambda,l}^{m}(a,c,A) L_{\sigma} f(z)\right)'}{I_{\lambda,l}^{m}(a,c,A) L_{\sigma} g(z)} - \beta = (1-\beta) h(z), \tag{62}$$

where $h(z)$ is given by (31), we find from (56) that

$$\frac{z\left(I_{\lambda,l}^{m}(a,c,A)f(z)\right)'}{I_{\lambda,l}^{m}(a,c,A)g(z)}=\frac{I_{\lambda,l}^{m}(a,c,A)zf'(z)}{I_{\lambda,l}^{m}(a,c,A)g(z)}$$

$$=\frac{z\left(I_{\lambda,l}^{m}(a,c,A)L_{\sigma}zf'(z)\right)'+\sigma\left(I_{\lambda,l}^{m}(a,c,A)L_{\sigma}zf'(z)\right)}{z\left(I_{\lambda,l}^{m}(a,c,A)L_{\sigma}g(z)\right)'+\sigma\left(I_{\lambda,l}^{m}(a,c,A)L_{\sigma}g(z)\right)}$$

$$=\frac{\frac{z\left(I_{\lambda,l}^{m}(a,c,A)L_{\sigma}zf'(z)\right)'}{I_{\lambda,l}^{m}(a,c,A)L_{\sigma}g(z)}+\sigma\frac{I_{\lambda,l}^{m}(a,c,A)L_{\sigma}zf'(z)}{I_{\lambda,l}^{m}(a,c,A)L_{\sigma}g(z)}}{\frac{z\left(I_{\lambda,l}^{m}(a,c,A)L_{\sigma}g(z)\right)'}{I_{\lambda,l}^{m}(a,c,A)L_{\sigma}g(z)}+\sigma}. \tag{63}$$

Since $g(z)\in S_{\lambda,l}^{*m}(a,c,A;\alpha)$, we know from Theorem 5 that $L_{\sigma}g(z)\in S_{\lambda,l}^{*m}(a,c,A;\alpha)$. Then, we can set

$$\frac{z\left(I_{\lambda,l}^{m}(a,c,A)L_{\sigma}g(z)\right)'}{I_{\lambda,l}^{m}(a,c,A)L_{\sigma}g(z)}-\alpha=(1-\alpha)H(z), \tag{64}$$

where $Re\{H(z)\}>0$. Then, substituting (62) and (64) into (63), we have

$$\frac{z\left(I_{\lambda,l}^{m}(a,c,A)f(z)\right)'}{I_{\lambda,l}^{m}(a,c,A)g(z)}=\frac{\frac{z\left(I_{\lambda,l}^{m}(a,c,A)L_{\sigma}zf'(z)\right)'}{I_{\lambda,l}^{m}(a,c,A)L_{\sigma}g(z)}+\sigma\left[\beta+(1-\beta)h(z)\right]}{\left[(1-\alpha)H(z)+\alpha\right]+\sigma}. \tag{65}$$

Also, we find from (62) that

$$z\left(I_{\lambda,l}^{m}(a,c,A)L_{\sigma}f(z)\right)'=\left(I_{\lambda,l}^{m}(a,c,A)L_{\sigma}g(z)\right)\left[(1-\beta)h(z)+\beta\right]. \tag{66}$$

Differentiating both sides of (66) with respect to z, we obtain

$$z\left(z\left(I_{\lambda,l}^{m}(a,c,A)L_{\sigma}f(z)\right)'\right)'=(1-\beta)zh'(z)\left(I_{\lambda,l}^{m}(a,c,A)L_{\sigma}g(z)\right)$$

$$+z\left(I_{\lambda,l}^{m}(a,c,A)L_{\sigma}g(z)\right)'\left[(1-\beta)h(z)+\beta\right], \tag{67}$$

that is,

$$\frac{z\left(z\left(I_{\lambda,l}^{m}(a,c,A)L_{\sigma}f(z)\right)'\right)'}{I_{\lambda,l}^{m}(a,c,A)L_{\sigma}g(z)}=(1-\beta)zh'(z)+\left[(1-\beta)h(z)+\beta\right]\left[(1-\alpha)H(z)+\alpha\right]. \tag{68}$$

Substituting (68) into (65), we find that

$$\frac{z\left(I_{\lambda,l}^{m}(a,c,A)f(z)\right)'}{I_{\lambda,l}^{m}(a,c,A)g(z)}-\beta=(1-\beta)h(z)+\frac{(1-\beta)zh'(z)}{\left[(1-\alpha)H(z)+\alpha\right]+\sigma}. \tag{69}$$

Then, by setting $u=h(z)=u_1+iu_2$ and $v=zh'(z)=v_1+iv_2$, we can define the function $\psi(u,v)$ by

$$\psi(u,v)=(1-\beta)u+\frac{(1-\beta)v}{\left[(1-\alpha)H(z)+\alpha\right]+\sigma},$$

where $(u,v)\in D=\mathbb{C}\times\mathbb{C}$. The remainder of our proof of Theorem 7 is similar to that of Theorem 3, so we choose to omit the analogous details involved.

Remark 10.

(i) Taking $m = s\ (s \in \mathbb{R})$, $\lambda = 1$, $a = \mu - 1 (\mu > 0)$, $c = 0$ and $A = 1$ in Theorems 5-7, we obtain the results obtained by Cho and Kim [8, Theorems 3.1-3.3 with $\varphi(z) = \psi(z) = \frac{1+z}{1-z}$];

(ii) Taking $a = \mu - 1 (\mu > 0)$, $c = 0$ and $A = 1$ in Theorems 5-7, we obtain the results obtained by Aouf and El-Ashwah [3, Theorems 4-6 with $\varphi(z) = \psi(z) = \frac{1+z}{1-z}$];

(iii) Taking $l = 0$, $a = \mu - 1 (\mu > 0)$, $c = 0$ and $A = 1$ in Theorems 5-7, we obtain the results obtained by Aouf et al. [2, Theorems 4-6 with $\varphi(z) = \psi(z) = \frac{1+z}{1-z}$].

Taking $a = c$ in Theorem 7, we obtain the following corollary.

Corollary 7. *Let* $\sigma > -\alpha$. *If* $f(z) \in K_{\lambda,l}^{m}(\beta, \alpha)$, *then* $L_{\sigma} f(z) \in K_{\lambda,l}^{m}(\beta, \alpha)$, where the subclass $K_{\lambda,l}^{m}(\beta, \alpha)$ is defined by (24).

Remark 11.

(i) Taking $\lambda = 1$, $m = \mu (\mu > 0)$ and $l = a - 1 (a > 0)$ in Corollary 7, we obtain the results obtained by Aouf [1, Theorem 7];

(ii) Taking $\lambda = l = 1$ and $m = \sigma (\sigma > 0)$ in Corollary 7, we obtain the results obtained by Liu [19, Theorem 7].

Taking $m = 0$ in Theorem 7, we obtain the following corollary.

Corollary 8. *Let* $\sigma > -\alpha$. *If* $f(z) \in K(a, c, A; \beta, \alpha)$, *then* $L_{\sigma} f(z) \in K(a, c, A; \beta, \alpha)$, where the subclass $K(a, c, A; \beta, \alpha)$ is defined by (28).

Remark 12. Taking $\alpha = \beta = 0$, $a = \mu - 1 (\mu > 0)$, $c = \lambda (\lambda > -1)$ and $A = 1$ in Corollary 8, we obtain the results obtained by Choi et al. [9, Theorem 6, with $\varphi(z) = \psi(z) = \frac{1+z}{1-z}$].

Theorem 8. *Let* $\sigma > -\alpha$. *If* $f(z) \in K_{\lambda,l}^{*m}(a, c, A; \beta, \alpha)$, *then*

$$L_{\sigma} f(z) \in K_{\lambda,l}^{*m}(a, c, A; \beta, \alpha).$$

Proof. Just as we derived Theorem 6 from Theorem 5. Easily, we can deduce Theorem 8 from Theorem 7. So we choose to omit the proof.

Taking $a = c$ in Theorem 8, we obtain the following corollary.

Corollary 9. *Let* $\sigma > -\alpha$. *If* $f(z) \in K_{\lambda,l}^{*m}(\beta, \alpha)$, *then* $L_{\sigma} f(z) \in K_{\lambda,l}^{*m}(\beta, \alpha)$, where the subclass $K_{\lambda,l}^{*m}(\beta, \alpha)$ is defined by (25).

Remark 13.

(i) Taking $\lambda = 1$, $m = \mu (\mu > 0)$ and $l = a - 1 (a > 0)$ in Corollary 9, we obtain the results obtained by Aouf [1, Theorem 8];

(ii) Taking $\lambda = l = 1$ and $m = \sigma(\sigma > 0)$ in Corollary 9, we obtain the results obtained by Liu [19, Theorem 8].

Taking $m = 0$ in Theorem 8, we obtain the following corollary.

Corollary 10. *Let* $\sigma > -\alpha$ *. If* $f(z) \in K^*(a,c,A;\beta,\alpha)$, *then* $L_\sigma f(z) \in K^*(a,c,A;\beta,\alpha)$, where the subclass $K^*(a,c,A;\beta,\alpha)$ is defined by (29).

4. CONCLUSION

From the results obtained in this paper, we can easily obtain the corresponding results of the well-known operators such as *Jung-Kim-Srivastava* operator, *Carlson-Shaffer* operator, *Noor* operator, *Ruscheweyeh* operator, *Salagean* operator, and others as a special choices of the parameters as mentioned before.

5. REFERENCES

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Research Article

Stability Analysis of Standing Matter Wave Dark Solitons in a Coupled Bose-Einstein Condensate

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Abstract: We study the existence and stability of standing matter waves in two quasi one-dimensional parallel coupled Bose-Einstein condensates in the presence of a magnetic trap. The system is modeled by linearly coupled Gross-Pitaevskii equations. In particular, the coupled dark soliton solutions are considered. The effect of changing strength of the magnetic trap on the stability of dark solitons is studied. It is found that the presence of a magnetic trap does not affect the stability of coupled dark solitons.

Keywords: Bose-Einstein condensate, magnetic trap, Gross-Pitaevskii equation, Josephson tunneling, stability

1. INTRODUCTION

A soliton is a nonlinear wave which does not alter its shape or speed during its motion. A Scottish engineer, John Scott Russell, was the first who observed a solitary wave on the Union Canal in Edinburgh in 1834. He named this wave as "the wave of translation". Later on, in 1965, Norman Zabusky and Martin Kruskal named this wave as a "soliton" while studying solitary waves in Korteweg-de Vries (KdV) equation [1].

It is a fact that there are several phenomena in physics, engineering and biology which can be explained by the physical and mathematical theory of solitons. For example, solitons are exactly suitable for fibre optics communications networks where in one second millions and billions of solitons carry information down fiber circuits for telephones, computers and televisions [2, 3]. The importance of solitons is apparent as they emerge as a solution of more than one hundred nonlinear partial differential equations [2].

The dynamics of solitons can be modeled by the nonlinear Schrödinger (NLS) equation. The NLS equation arises in the description of various physical phenomena such as Bose-Einstein Condensates (BEC) [4], non-linear optics [4, 5], non-linear water waves, non-linear acoustics [6], plasma waves [7] and so on. From a mathematical view point, on the Euclidean space, this equation has been studied since the seventies [8]. Although the NLS equation has infinitely many solutions, the mostly studied solutions are plane wave solution, bright soliton, dark soliton, etc.

Dark solitons are the basic indispensable envelope excitations sustained in non-linear dispersive media and comprise of a swift dip in the intensity of a wide pulse or a continuous waveguide background

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with a jump in its phase at its intensity minimum. Not only theoretically but many experimental observations and results on dark solitons exist, such as pulses in optical fibers (from which the name dark was conceived) [9], thin magnetic films [10], movement of static kink in a shallow liquid driven parametrically [11], standing waves in mechanical systems [12], and many more.

The study on matter wave dark solitons continue to be an interesting subject. In one dimension, the criterion for the dynamical stability of dark soliton was given in [13]. The snake instability was crushed and the dark soliton was stabilized by strongly confining the radial motion and by keeping the radial frequency greater than the mean field interaction of the particles. The experimental and theoretical studies of vortices in Bose-Einstein condensates were presented in [14].

The idea of electron tunneling also called Josephson tunneling between two superconductors linked with each other by a very thin insulator [15] was presented by Josephson in 1962. Such tunneling in BEC was predicted by Smerzi et al. [16, 17]. Josephson tunneling for a single and an arrangement of short Bose-Josephson junction [18] was realized experimentally. The idea of Bose-Josephson junction was extended to long Bose-Josephson junction in [19]. This junction was similar to long superconducting Josephson junction. It was proposed in [19] that atomic vortices could be seen in coupled BEC that are weakly linked with each other and that these vortices are analogues to Josephson fluxons in superconducting long Josephson junction [20]. Moreover, it was shown that the atomic Josephson vortices can be transformed to a matter wave dark soliton and vice versa at a critical value of coupling strength. Josephson tunneling of matter wave dark solitons in a double-well potential was investigated in [21].

In this work, we consider the existence and stability of matter wave dark solitons in two coupled cigar-shaped BEC with a magnetic trap. In particular, we investigate the effects of change in the strength of a magnetic trap on the stability of dark solitons in BEC.

2. MATHEMATICAL MODEL AND DESCRIPTION

Let us consider a system of two coupled cigar-shaped BEC under the influence of an external magnetic trap. The intra atomic interaction is assumed to be repulsive. The system can be described by two coupled one-dimensional nonlinear Schrodinger equations which can be written as

$$i\,\frac{\partial u_1}{\partial \mathrm{t}} = -\frac{1}{2}\,\frac{\partial^2 u_1}{\partial \mathrm{x}^2} + \alpha|u_1|^2 u_1 + \beta u_1 - \gamma u_2 + \mho_{ext}\; u_1 \tag{1}$$

$$i\,\frac{\partial u_2}{\partial \mathrm{t}} = -\frac{1}{2}\,\frac{\partial^2 u_2}{\partial \mathrm{x}^2} + \alpha|u_2|^2 u_2 + \beta u_2 - \gamma u_1 + \mho_{ext}\; u_2\,, \tag{2}$$

where x and t represent the spatial and temporal variables respectively. u_1 and u_2 denote the wave functions of atoms of BEC in the two wells of a magnetic trap. The parameters $\alpha,\ \beta$ and γ represent respectively the nonlinearity coefficient, the chemical potential and the coupling strength between the two condensates. $\mho_{ext}$ is the external magnetic trap and is given as

$$\mho_{ext} = \frac{1}{2}\,\Omega^2 x^2, \tag{3}$$

where Ω denotes the strength of external magnetic trap and i represents iota.

When $\gamma = 0$, i.e. the two condensates are uncoupled, the dynamics of matter wave dark solitons in BEC with an external potential was studied theoretically [22, 23] and experimentally [24, 25]. Intriguing

phenomena on the joint behavior of a quantum degenerate boson gas, for instance, oscillations of solitons [24] and shifts in frequency due to collisions were observed.

In this study, we consider the case when $\gamma \neq 0$. For the steady state solution, putting $\frac{\partial u_1}{\partial t} = 0 = \frac{\partial u_2}{\partial t}$, we obtain

$$\frac{1}{2}\frac{\partial^2 u_1}{\partial x^2} - \alpha|u_1|^2 u_1 - \beta u_1 + \gamma u_2 - v_{ext}\ u_1 = 0, \tag{3}$$

$$\frac{1}{2}\frac{\partial^2 u_2}{\partial x^2} - \alpha|u_2|^2 u_2 - \beta u_2 + \gamma u_1 - v_{ext}\ u_2 = 0. \tag{4}$$

Discretizing eq.(3) and eq.(4) using central difference approximations, we obtain

$$\frac{u_{1,m+1} - 2u_{1,m} + u_{1,m-1}}{2\Delta x^2} - \alpha|u_{1,m}|^2 u_{1,m} - \beta u_{1,m} + \gamma u_{2,m} - v_{ext}\ u_{1,m} = 0, \tag{5}$$

$$\frac{u_{2,m+1} - 2u_{2,m} + u_{2,m-1}}{2\Delta x^2} - \alpha|u_{2,m}|^2 u_{2,m} - \beta u_{2,m} + \gamma u_{1,m} - v_{ext}\ u_{2,m} = 0, \tag{6}$$

where $m = 1,2,\dots,M$.

Eq. (5) and eq. (6) represent a coupled system of nonlinear algebraic equations. We solve this system numerically using Newton's method with the Neumann boundary conditions $u_{n,0} = u_{n,1}$ and $u_{n,M} = u_{n,M+1}$, $n = 1,2$ and obtain linearly coupled dark soliton solution as shown in Fig. 1.

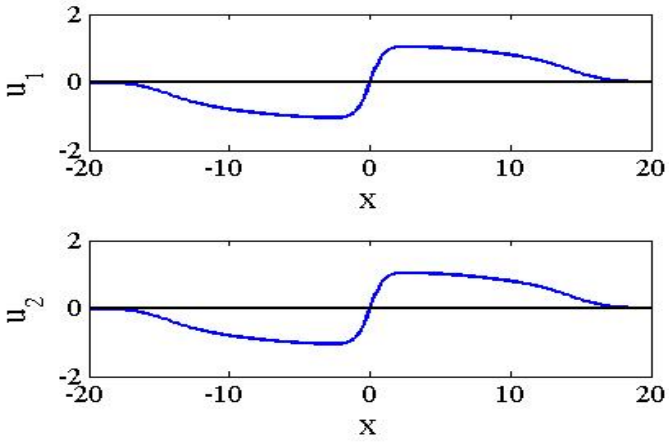

Fig. 1. Numerically obtained coupled dark soliton solution for the parameter values $\alpha = 1$, $\beta = 1$, $\gamma = 0.15$ and $\Omega = 0.1$. The real and imaginary parts of solution are represented by blue curves and black lines, respectively.

3. STABILITY OF COUPLED DARK SOLITONS

In order to discuss the stability of dark soliton, we first assume that $u_1^{(0)}$ and $u_2^{(0)}$ are the static solutions of system of eq. (1) and eq. (2). Let us perturb these solutions $u_1^{(0)}$ and $u_2^{(0)}$ by adding small perturbations $\eta_1(x,t)$ and $\eta_2(x,t)$ in them respectively, i.e.

$$u_1(x,t) = u_1^{(0)}(x) + \eta_1(x,t), \tag{7}$$

$$u_2(x,t) = u_2^{(0)}(x) + \eta_2(\mathrm{x},\mathrm{t}), \tag{8}$$

Substituting these values of $u_1(x,t)$ and $u_2(x,t)$ from eq. (7) and eq. (8) into eq. (1) and eq. (2), we get

$$i\frac{\partial\eta_1}{\partial \mathrm{t}} = -\frac{1}{2}\left(\frac{\partial^2 u_1^{(0)}}{\partial \mathrm{x}^2} + \frac{\partial^2\eta_1}{\partial \mathrm{x}^2}\right) + \alpha\left(u_1^{(0)}+\eta_1\right)^2\overline{\left(u_1^{(0)}+\eta_1\right)} - \beta\left(u_1^{(0)}+\eta_1\right) + \mathscr{v}_{ext}\left(u_1^{(0)}+\eta_1\right) - \gamma\left(u_2^{(0)}+\eta_2\right), \tag{9}$$

$$i\frac{\partial\eta_2}{\partial \mathrm{t}} = -\frac{1}{2}\left(\frac{\partial^2 u_2^{(0)}}{\partial \mathrm{x}^2} + \frac{\partial^2\eta_2}{\partial \mathrm{x}^2}\right) + \alpha\left(u_2^{(0)}+\eta_2\right)^2\overline{\left(u_2^{(0)}+\eta_2\right)} - \beta\left(u_2^{(0)}+\eta_2\right) + \mathscr{v}_{ext}\left(u_2^{(0)}+\eta_2\right) - \gamma\left(u_1^{(0)}+\eta_1\right), \tag{10}$$

where bar represents the complex conjugate. Keeping in view that $u_1^{(0)}$ and $u_2^{(0)}$ are the solutions of system of eq. (3) and eq. (4) and assuming that the perturbations η_1 and η_2 are so small that their squares and higher power terms can be neglected, the above eq. (9) and eq. (10) can be written as

$$i\frac{\partial\eta_1}{\partial \mathrm{t}} = -\frac{1}{2}\frac{\partial^2\eta_1}{\partial \mathrm{x}^2} + 2\alpha|u_1^{(0)}|^2\eta_1 + \alpha\left(u_1^{(0)}\right)^2\overline{\eta_1} - \beta\eta_1 + \mathscr{v}_{ext}\,\eta_1 - \gamma\eta_2, \tag{11}$$

$$i\frac{\partial\eta_2}{\partial \mathrm{t}} = -\frac{1}{2}\frac{\partial^2\eta_2}{\partial \mathrm{x}^2} + 2\alpha|u_2^{(0)}|^2\eta_2 + \alpha\left(u_2^{(0)}\right)^2\overline{\eta_2} - \beta\eta_2 + \mathscr{v}_{ext}\,\eta_2 - \gamma\eta_1. \tag{12}$$

Taking the complex conjugate of these equations, we obtain

$$-i\frac{\partial\overline{\eta_1}}{\partial \mathrm{t}} = -\frac{1}{2}\frac{\partial^2\overline{\eta_1}}{\partial \mathrm{x}^2} + 2\alpha|u_1^{(0)}|^2\overline{\eta_1} + \alpha\left(\overline{u_1^{(0)}}\right)^2\eta_1 - \beta\overline{\eta_1} + \mathscr{v}_{ext}\,\overline{\eta_1} - \gamma\overline{\eta_2}, \tag{13}$$

$$-i\frac{\partial\overline{\eta_2}}{\partial \mathrm{t}} = -\frac{1}{2}\frac{\partial^2\overline{\eta_2}}{\partial \mathrm{x}^2} + 2\alpha|u_2^{(0)}|^2\overline{\eta_2} + \alpha\left(\overline{u_2^{(0)}}\right)^2\eta_2 - \beta\overline{\eta_2} + \mathscr{v}_{ext}\,\overline{\eta_2} - \gamma\overline{\eta_1}. \tag{14}$$

For simplicity we replace η_i by χ_i and $\overline{\eta_i}$ by ξ_i, where $i = 1,2$ in equations (11), (12), (13) and (14) to obtain

$$i\frac{\partial\chi_1}{\partial \mathrm{t}} = -\frac{1}{2}\frac{\partial^2\chi_1}{\partial \mathrm{x}^2} + 2\alpha|u_1^{(0)}|^2\chi_1 + \alpha\left(u_1^{(0)}\right)^2\xi_1 - \beta\chi_1 + \mathscr{v}_{ext}\,\chi_1 - \gamma\chi_2 = \lambda\chi_1, \tag{15}$$

$$i\frac{\partial\chi_2}{\partial \mathrm{t}} = -\frac{1}{2}\frac{\partial^2\chi_2}{\partial \mathrm{x}^2} + 2\alpha|u_2^{(0)}|^2\chi_2 + \alpha\left(u_2^{(0)}\right)^2\xi_2 - \beta\chi_2 + \mathscr{v}_{ext}\,\chi_2 - \gamma\chi_1 = \lambda\chi_2, \tag{16}$$

$$i\frac{\partial\xi_1}{\partial \mathrm{t}} = \frac{1}{2}\frac{\partial^2\xi_1}{\partial \mathrm{x}^2} - 2\alpha|u_1^{(0)}|^2\xi_1 - \alpha\left(\overline{u_1^{(0)}}\right)^2\chi_1 + \beta\xi_1 - \mathscr{v}_{ext}\,\xi_1 + \gamma\xi_2 = \lambda\xi_1, \tag{17}$$

$$i\frac{\partial\xi_2}{\partial \mathrm{t}} = \frac{1}{2}\frac{\partial^2\xi_2}{\partial \mathrm{x}^2} - 2\alpha|u_1^{(0)}|^2\xi_2 - \alpha\left(\overline{u_2^{(0)}}\right)^2\chi_2 + \beta\xi_2 - \mathscr{v}_{ext}\,\xi_2 + \gamma\xi_1 = \lambda\xi_2, \tag{18}$$

where λ is a scalar representing the eigenvalues.

Discretizing equations (15), (16), (17) and (18) gives

$$-\frac{\chi_{1,m+1}-2\chi_{1,m}+\chi_{1,m-1}}{2\Delta x^2}+2\alpha|u_{1,m}^{(0)}|^2\chi_{1,m}+\alpha\left(u_{1,m}^{(0)}\right)^2\xi_{1,m}-\beta\chi_{1,m}+\upsilon_{ext}\,\chi_{1,m}-\gamma\chi_{2,m}=\lambda\chi_{1,m}, \tag{19}$$

$$-\frac{\chi_{2,m+1}-2\chi_{2,m}+\chi_{2,m-1}}{2\Delta x^2}+2\alpha|u_{2,m}^{(0)}|^2\chi_{2,m}+\alpha\left(u_{2,m}^{(0)}\right)^2\xi_{2,m}-\beta\chi_{2,m}+\upsilon_{ext}\,\chi_{2,m}-\gamma\chi_{1,m}=\lambda\chi_{2,m}, \tag{20}$$

$$\frac{\xi_{1,m+1}-2\xi_{1,m}+\xi_{1,m-1}}{2\Delta x^2}-2\alpha|u_{1,m}^{(0)}|^2\xi_{1,m}-\alpha\left(\overline{u_{1,m}^{(0)}}\right)^2\chi_{1,m}+\beta\xi_{1,m}-\upsilon_{ext}\,\xi_{1,m}+\gamma\xi_{2,m}=\lambda\xi_{1,m}, \tag{21}$$

$$\frac{\xi_{2,m+1}-2\xi_{2,m}+\xi_{2,m-1}}{2\Delta x^2}-2\alpha\left|u_{2,m}^{(0)}\right|^2\xi_{2,m}-\alpha\left(\overline{u_{2,m}^{(0)}}\right)^2\chi_{2,m}+\beta\xi_{2,m}-\upsilon_{ext}\,\xi_{2,m}+\gamma\xi_{1,m}=\lambda\xi_{2,m}, \tag{22}$$

where $m=1,2,\dots,M$. Using the Neumann boundary conditions $\chi_{n,0}=\chi_{n,1}$ and $\xi_{n,M}=\xi_{n,M+1},\ n=1,2,$ the above system of equations (19), (20), (21) and (22) can be expressed as an eigenvalue problem

$$AX=\lambda X,$$

where

$$\mathrm{A}=\begin{bmatrix} A_1 & G & B_1 & 0 \\ G & A_2 & 0 & B_2 \\ -\overline{B_1} & 0 & -A_1 & -G \\ 0 & -\overline{B_2} & -G & -A_2 \end{bmatrix},$$

$$A_1=\begin{bmatrix} \frac{1}{2\Delta x^2}+2\alpha|u_{1,1}^{(0)}|^2-\beta+\upsilon_{ext} & \frac{-1}{2\Delta x^2} & 0 & 0 & \dots & 0 \\ \frac{-1}{2\Delta x^2} & \frac{1}{\Delta x^2}+2\alpha|u_{1,2}^{(0)}|^2-\beta+\upsilon_{ext} & \frac{-1}{2\Delta x^2} & 0 & \dots & 0 \\ 0 & \frac{-1}{2\Delta x^2} & \frac{1}{\Delta x^2}+2\alpha|u_{1,3}^{(0)}|^2-\beta+\upsilon_{ext} & \frac{-1}{2\Delta x^2} & \dots & 0 \\ & \ddots & \ddots & \ddots & \ddots & \\ & & \ddots & \ddots & \ddots & \\ 0 & 0\dots & \frac{-1}{2\Delta x^2} & \frac{1}{2\Delta x^2}+2\alpha|u_{1,M}^{(0)}|^2-\beta+\upsilon_{ext} & & \end{bmatrix},$$

$$A_2=\begin{bmatrix} \frac{1}{2\Delta x^2}+2\alpha|u_{2,1}^{(0)}|^2-\beta+\upsilon_{ext} & \frac{-1}{2\Delta x^2} & 0 & 0 & \dots & 0 \\ \frac{-1}{2\Delta x^2} & \frac{1}{\Delta x^2}+2\alpha|u_{2,2}^{(0)}|^2-\beta+\upsilon_{ext} & \frac{-1}{2\Delta x^2} & 0 & \dots & 0 \\ 0 & \frac{-1}{2\Delta x^2} & \frac{1}{\Delta x^2}+2\alpha|u_{2,3}^{(0)}|^2-\beta+\upsilon_{ext} & \frac{-1}{2\Delta x^2} & \dots & 0 \\ & \ddots & \ddots & \ddots & \ddots & \\ & & \ddots & \ddots & \ddots & \\ 0 & 0\dots & \frac{-1}{2\Delta x^2} & \frac{1}{2\Delta x^2}+2\alpha|u_{2,M}^{(0)}|^2-\beta+\upsilon_{ext} & & \end{bmatrix},$$

$$B_1 = \begin{bmatrix} \alpha\left(u_{1,1}^{(0)}\right)^2 & 0 & 0 & \dots & 0 \\ 0 & \alpha\left(u_{1,2}^{(0)}\right)^2 & 0 & \dots & 0 \\ 0 & 0 & \alpha\left(u_{1,3}^{(0)}\right)^2 & \dots & 0 \\ & & \ddots & & \\ & & & \ddots & \\ 0 & 0 & 0 & \dots & \alpha\left(u_{1,M}^{(0)}\right)^2 \end{bmatrix},$$

$$B_2 = \begin{bmatrix} \alpha\left(u_{2,1}^{(0)}\right)^2 & 0 & 0 & \dots & 0 \\ 0 & \alpha\left(u_{2,2}^{(0)}\right)^2 & 0 & \dots & 0 \\ 0 & 0 & \alpha\left(u_{2,3}^{(0)}\right)^2 & \dots & 0 \\ & & \ddots & & \\ & & & \ddots & \\ 0 & 0 & 0 & \dots & \alpha\left(u_{2,M}^{(0)}\right)^2 \end{bmatrix},$$

$$G = \begin{bmatrix} -\gamma & 0 & 0 & \dots & 0 \\ 0 & -\gamma & 0 & \dots & 0 \\ 0 & 0 & -\gamma & \dots & 0 \\ & & & \ddots & \\ & & & & \ddots \\ 0 & 0 & 0 & \dots & -\gamma \end{bmatrix}.$$

The solution will be unstable if the imaginary part of at least one of the eigenvalues is positive.

We find the eigenvalues of the stability matrix A and are shown in Fig. 2. One can see that all eigenvalues are lying on the horizontal axis except a pair of eigenvalues which is lying on the vertical axis and depicting the instability of the coupled dark soliton solution. In order to confirm the results found, we solve the system of eq. (1) and eq. (2) numerically by perturbing the solution shown in Fig. 1 and use the 4th order Runge-Kutta method. The time evolution of the coupled dark soliton is shown in Fig. 3. The radiation are emerging at nearly $t = 40$ and reveals that the solution is unstable which justifies the results

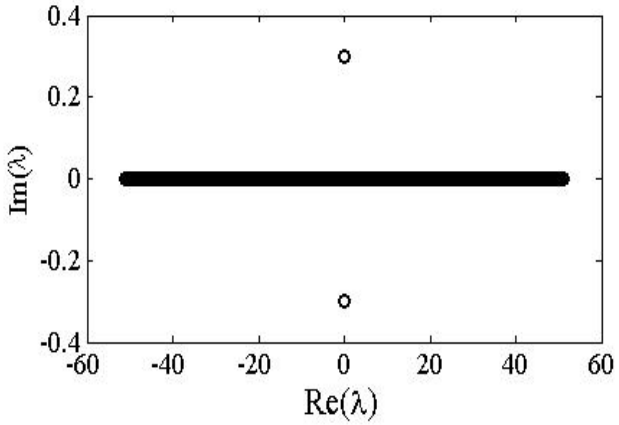

Fig. 2. The eigenvalues structure for the solution shown in Fig. 1. The two eigenvalues are lying on the vertical axis and depicts that the solution is unstable.

already obtained. We then investigate the stability of the coupled dark soliton for different values of Ω and noticed that the critical value of the coupling parameter γ is γ_c which in our case is nearly 0.334. This value remains unchanged with Ω as shown in Fig. 4. This means that the magnetic trap does not affect the critical value of the stability of the solution. Thus the coupled dark soliton solution exists and is unstable for $\gamma < 0.334$ but becomes stable for $\gamma > 0.334$.

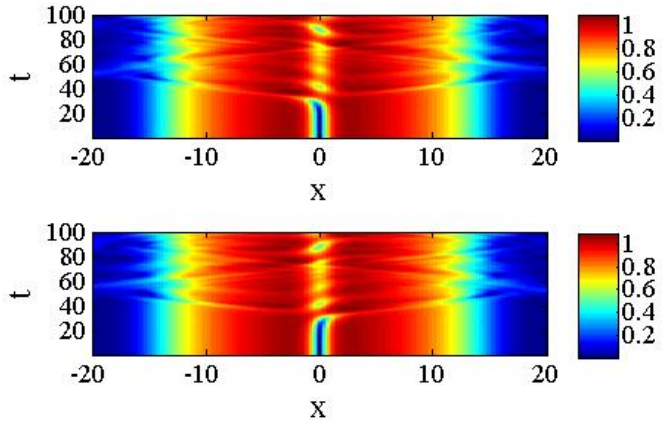

Fig. 3. The evolution of time for the solution shown in Fig. 1. The upper panel corresponds to $|u_1|$ and lower panel to $|u_2|$. The emergence of radiation in both panels shows the instability of the solution.

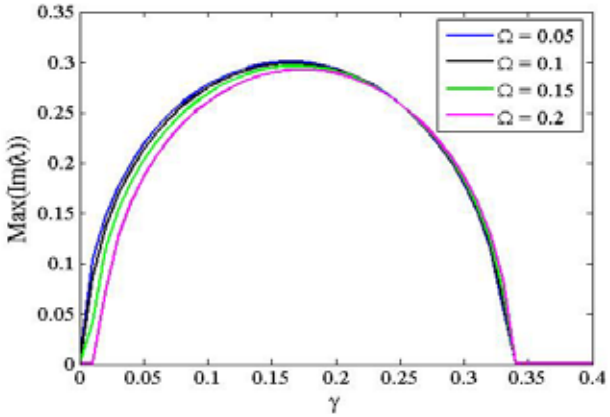

Fig. 4. Stability curves for the coupled dark soliton solution for distinct values of trapping strength Ω. The critical value remains unchanged for each value of Ω showing that the magnetic trap does not affect the stability of coupled dark soliton solution.

4. CONCLUSIONS

In this paper, we have considered the existence and stability of standing matter wave dark solitons in two quasi one-dimensional parallel coupled BEC in a magnetic trap. Especially, the stability of coupled dark soliton solution has been investigated while varying the strength of the magnetic trap. It has been found that a critical value γ_c of the coupling parameter exists which remains unchanged with the strength of the magnetic trap. The coupled dark soliton solution exists and remains unstable for $\gamma < \gamma_c$ and is stable for $\gamma > \gamma_c$.

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Research Article

Evaluation of Techniques for the Improvement of Subgrade Soils in Flood and Rainfall Inundation Affected Areas

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Abstract: Highways are amongst the most costly resources contributing directly to the growth of any country's economy. Subgrade soils as component of highways deteriorate normally from numerous factors resulting into flushing or excessive settlements of embankment involving huge maintenance costs. In this research, an attempt has been made to evaluate suitable technique for stabilization of commonly available subgrade soils of Pakistan based on cost effectiveness and ease in construction. The soils identified as A-3(0) by American Association of State Highway and Transportation Officials (AASHTO) criteria has been stabilized with conventional additives i.e. cement and bitumen in this research. The optimum content of each additive for stabilization based on their relative effectiveness was used. Trials were also made to economize the cost of stabilization from both conventional additives by controlled replacing of them with waste polythene and polyester fibers. The construction methodology for stabilization using waste fibers was also proposed. Cement was observed to be the most effective stabilizer with respect to strength and durability for A-3(0) soils. Bitumen was found effective but uneconomical for A-3(0) soils. Waste polythene and polyester wastes (organic materials) have potential to economize the cost of stabilization with cement and bitumen for A-3(0) soils. However, long term degradation of these organic materials in soil stabilized mixtures needs further exploration.

Keywords: Subgrade soils, stabilization, cement, bitumen, polythene, polyester

1. INTRODUCTION

Highways are the road passages which are constructed to facilitate communities in cities, districts, villages, etc. for domestic, professional and trading purposes. As the world is becoming the global village the highways are also extending beyond the borders of the countries. Motorways and expressways are the key types of highways. The highway networks of most of the countries are administered by government controlled authorities. In Pakistan the national network of highways are administered by National Highway Authority (NHA). The provincial highways of Pakistan are administered by provincial highway section of Communication and Work Department.

Highways and roads network as communication means are the backbone of the future development prospects of any country. Pakistan being an underdeveloped country has been lagging in the sufficient provisions of these communication means. However, it should be recognized that highways and road network will act as catalyst in future development of any country. Due to high initial construction cost the new highway projects mostly remained among descending preferences of authorities in developing countries. Fig. 1 shows existing and planned highways network in Pakistan. The Grand Trunk Road (N-5) is the longest highway of the country and most of the other highways of Pakistan are extending from it. M-2 was the first motorway section that was constructed in Pakistan followed by M-1 and M-3. Currently work on M-4 is under progress and M-5 to M-9 is in pipeline.

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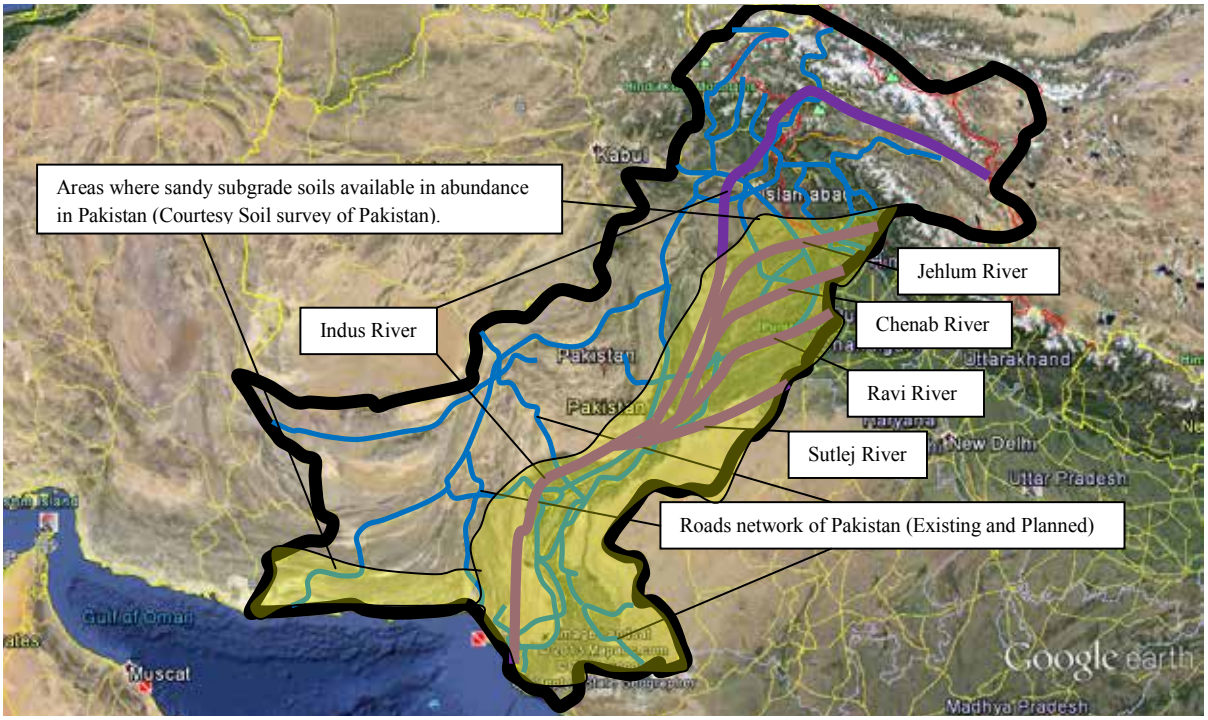

Fig. 1. Orientation of major rivers and highways of Pakistan (Courtesy: Google Earth, US Dept. of State Geographer, 2015).

Table 1. Details and characteristics of different highway components used in Pakistan.

Description	Composition	Sources of Materials*	Typical Thickness Used (mm)[8]**
Asphaltic wearing course	Asphalt	NRL, ARL	38-50
	Aggregates	Margallah, Sargodha, Ubhanshah	
Asphaltic base course	Asphalt	NRL, ARL	75-125
	Aggregates	Margallah, Sargodha, Ubhanshah	
Base course	Aggregates	Margallah, Sargodha, Ubhanshah	125-250
Subbase course	Aggregates	Margallah, Sargodha, Ubhanshah	250-350
Subgrade	Aggregates	-	Variable depending upon terrain and requirement of cut or fill.

NRL = National Refinery Limited - Karachi, ARL = Attock Refinery Limited - Attock,
*Approved by National Highway Authority (NHA)
** Depends on axle load, traffic type & frequency. Based on California Bearing Ratio (CBR) Test [8] Guidelines

Most of the highways shown in Fig. 1 are crossing or passing parallel to the route of water passages like rivers and canals. Due to monsoon rains the rise in water levels of five major rivers of Pakistan i.e. Ravi, Chenab, Jehlum, Sutlej, Indus along with 58,000 km length of canal system are the sources of floods in Pakistan which causes normally deterioration to subgrade layers of roads and highways.

The main components of highways are shown in Fig. 2. The thicknesses of each component depend on loading requirement of the highway and

strength of materials [1]. Table 1 presents a summary of guidelines about the characteristics of these components in Pakistan.

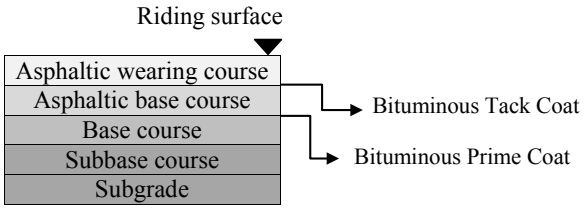

Fig. 2. Components of highways.

Subgrade as aggregate is a common soil material. During construction of new highways the soils along the routes are utilized as subgrade subjected to fulfillment of design strength [2, 3]. If the soils are weak in strength than improvement of the soils is carried out to enhance its durability against water infiltration and environmental changes [4]. Depending on the type of soil and scale of improvement various additives like cement, lime, bitumen and fly ash are used to improve the strength of subgrade soils [4, 5, 6]. By addition of these additives not only strength is improved but the durability of the material is also enhanced [7].

The subgrade materials used in roads and highways of Pakistan are normally not stabilized. Due to environmental changes and water infiltration in unstabilized soils used in roads and highways at different parts of Pakistan these subgrade materials had been damaged. That cause lot of maintenance cost incurrence each year by different provincial and federal road maintenance agencies. Pakistan has lot of prospects for the construction of new highways in coming years. Keeping consideration in view, this research has been initiated with aim to study the best possible additive for improving the strength of commonly available subgrade soil of Pakistan in respect of cost as well as ease of construction to enhance its durability against environmental and water associated degradation.

2. MATERIALS AND METHODS

The objectives of this research were achieved by adopting following methodology:

The identification of locations, where potential subgrade material used in roads and highways is available in abundance. For that purpose the database, literature and survey records of Soil Survey of Pakistan have been consulted. In addition, literature from geotechnical investigation reports and Geological Survey of Pakistan was also studied.

Collection of disturbed and representative identified alluvial sandy soil samples. Determination of engineering properties of soil by performing laboratory tests, i.e., sieve analysis, specific gravity, description and identification of soil, shear strength by direct shear, standard and modified proctor compaction. To enhance the confidence three replications of each test were carried out. The soils were stabilized by cement and bitumen. For determination of the strength of stabilized soil unconfined compression test [8, 9, 10] was employed on three representative samples with three replications. The cement used was ordinary port land type (OPC) manufactured by Mapple Leaf confirming to quality requirements [10]. The cement stabilized reconstituted samples were cured as per guidelines [10] of curing for 7, 14 and 28 days.

The subgrade soils were stabilized by locally available medium curing (MC) and rapid curing (RC) bitumen [11, 12]. Three samples each with three replicates were evaluated. Kerosene oil was used as solvent to cut back both MC and RC during preparation of bitumen samples. For estimation of preliminary quantity of MC and RC following equation was used [13]:

$$p = 100\,[(0.02\,a + 0.07\,b + 0.15\,c + 0.20\,d\,)/(100 - S)] \quad (1)$$

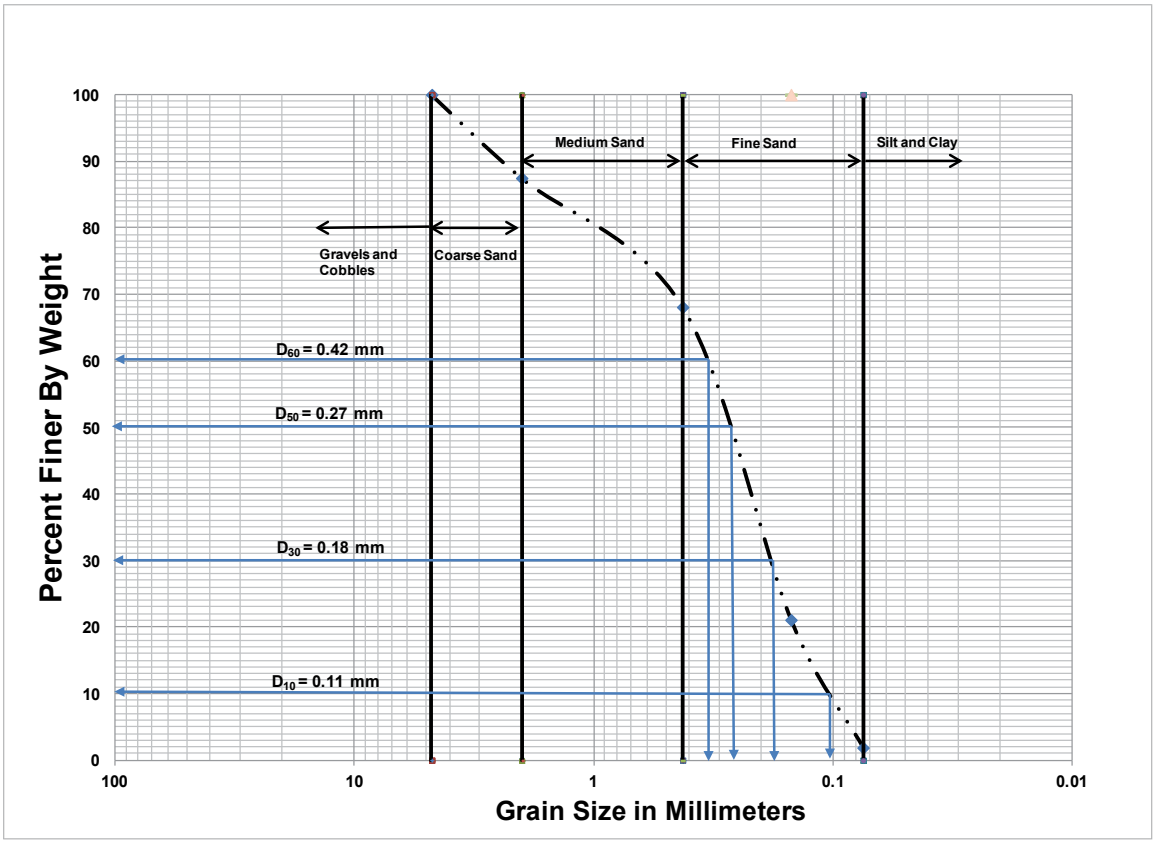

Fig. 3. Grainsize analysis of the soil sample.

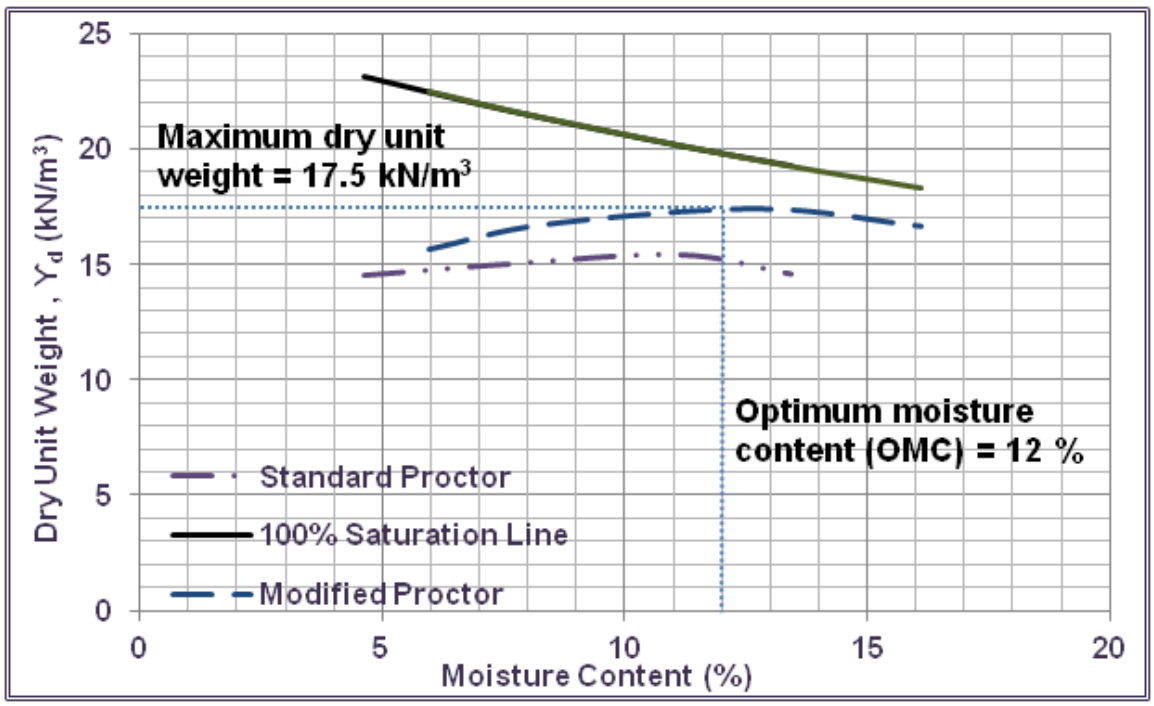

Fig. 4. Compaction test curve of the A-3 soil by modified and standard proctor test methods.

Table 2. Geotechnical properties of the investigated soil sample

Soil Parameters	Laboratory Tests/ Empirical Methods	Results	Test Methodology
Coefficient of Concavity, $C_c = (D_{30})^2 / (D_{60}\, D_{10})$	Grain size analysis	0.70	ASTM D422[15]
Coefficient of Uniformity, $C_u = D_{60} / D_{10}$	Grain size analysis	3.82	ASTM D422[15]
Plasticity Index	Atterberg limits	Non Plastic	ASTM D4318[16]
Specific gravity	Specific gravity	2.66	ASTM D854[17]
Group Index	Grain size analysis and Atterberg limits	0	ASTM D422[15] & ASTM D4318[16]
Drained friction angle (ϕ')	Direct shear	33.1^0	ASTM D3080[18]
Maximum dry density	Modified proctor	17.50 kN/m^3	ASTM D698[19]
Optimum moisture content	Modified proctor	12.0 %	ASTM D698[19]
California bearing ratio (CBR)	Soaked CBR Test	17.0 %	ASTM D1883[8]
Resilient Modulus (MPa)	Empirical Method	48	NCHRP[20]

where

p = MC / RC bitumen by weight of dry aggregate;
a = Aggregate percentage retained on No. 50 sieve;
b = Aggregate percentage passing No. 50 sieve and retained on No. 100 sieve;
c = Aggregate percentage passing No. 100 and retained on No. 200 sieve;
d = Aggregate percentage passing No. 200;
S = percent solvent

The polythene and polyester materials can also be used to stabilize subgrade soils [14]. According to environment protection agency (EPA) of Pakistan, both of these materials are available in abundance in Pakistan as waste material whose safe disposal to environment is costly and time consuming. Therefore, as the part of this research; an evaluation has been made to study the stabilization of subgrade soils using polythene and polyester waste materials. Polythene and polyester fiber samples taken from waste plastic bags and waste packing materials were shredded in form of threads. Three samples of soil were prepared against three percentages of both polythene and polyester fibers to evaluate its improvement through stabilization. Three replications were performed to enhance precision and accuracy.

3. RESULTS AND DISCUSSION

In provinces of Punjab and Sindh alluvial soils were found in abundance (Fig. 1) especially along the deltas and bunds of rivers (Ravi, Chenab, Jehlum, Sutlej, Indus), canals, streams etc. These soils are loose at its deposition location; however, as a material it does have potential to act as a useful subgrade against environmental changes and rainfall indentation. According to soil survey of Pakistan, in most locations its depth of deposition is even extending beyond 50 m. Samples of soils were taken from three locations in the forthcoming routes of the motorways (M-4, M-5 and M-6) to be constructed consulting the database of Soil Survey of Pakistan. All three samples were found similar in physical appearance with fraction of variation in grains contents. The typical grain size analysis curve of the soil used for research is shown in Fig. 3. The moisture density relation curve of the soil by standard and

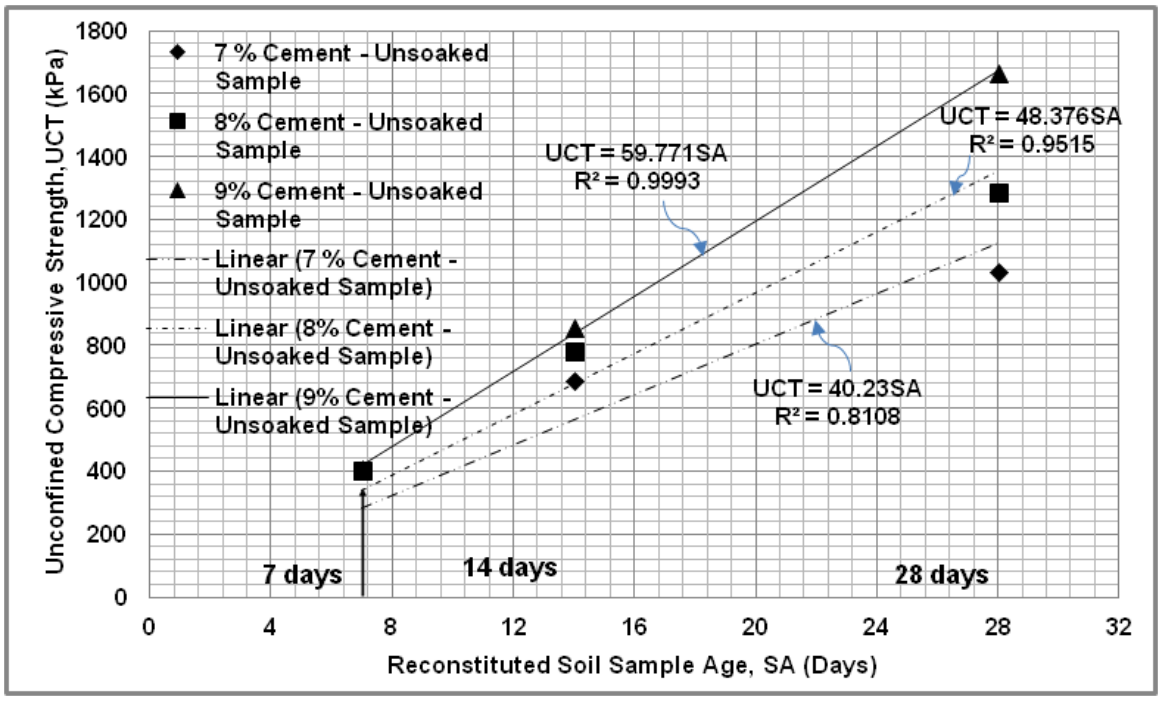

Fig. 5. Variation in cement stabilized soil unconfined compressive strength with curing age.

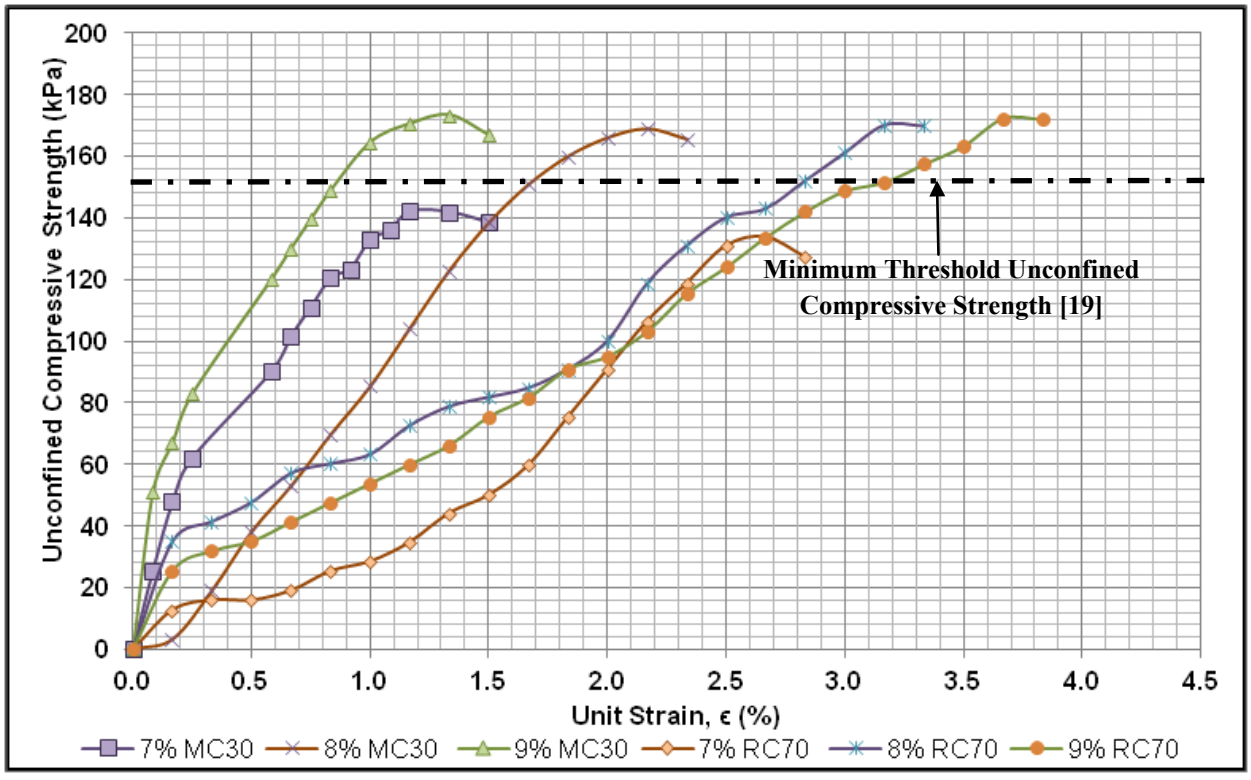

Fig. 6. Variation in soil unconfined compressive strength with bitumen type and content.

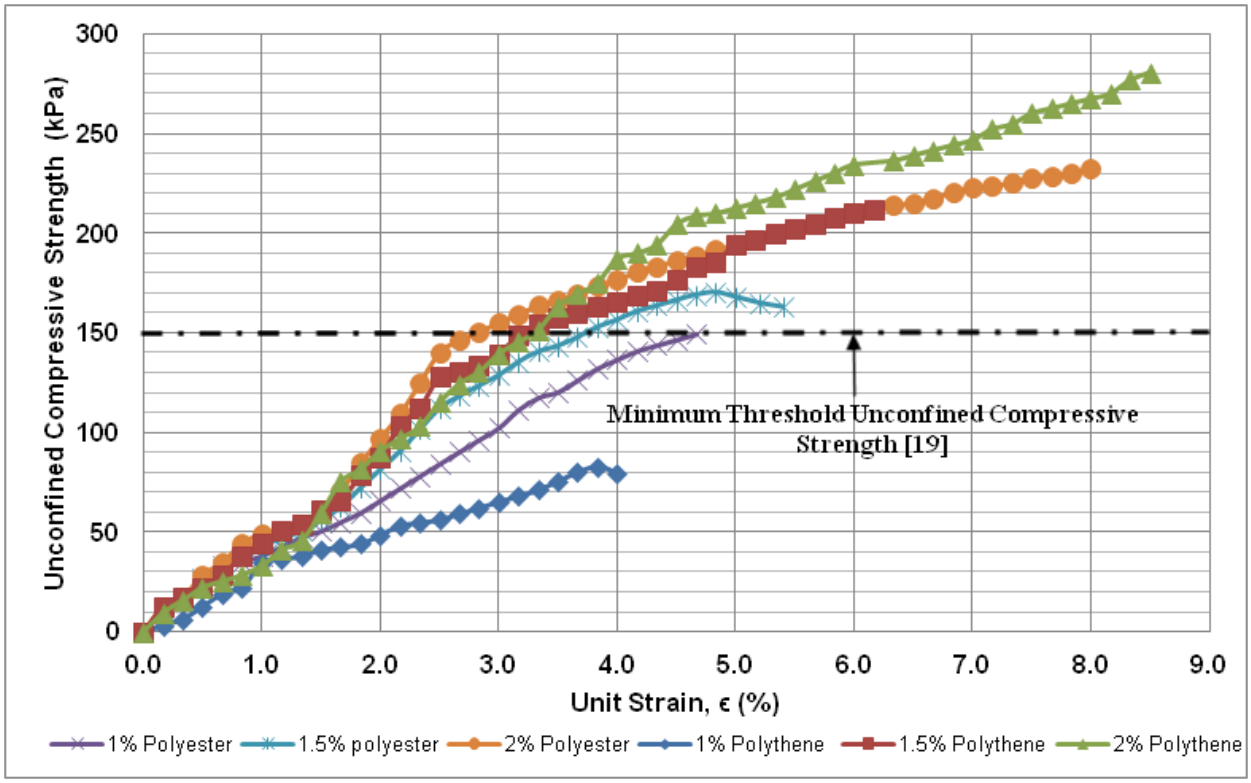

Fig. 7. Variation in soil unconfined compressive strength with fibers type and content.

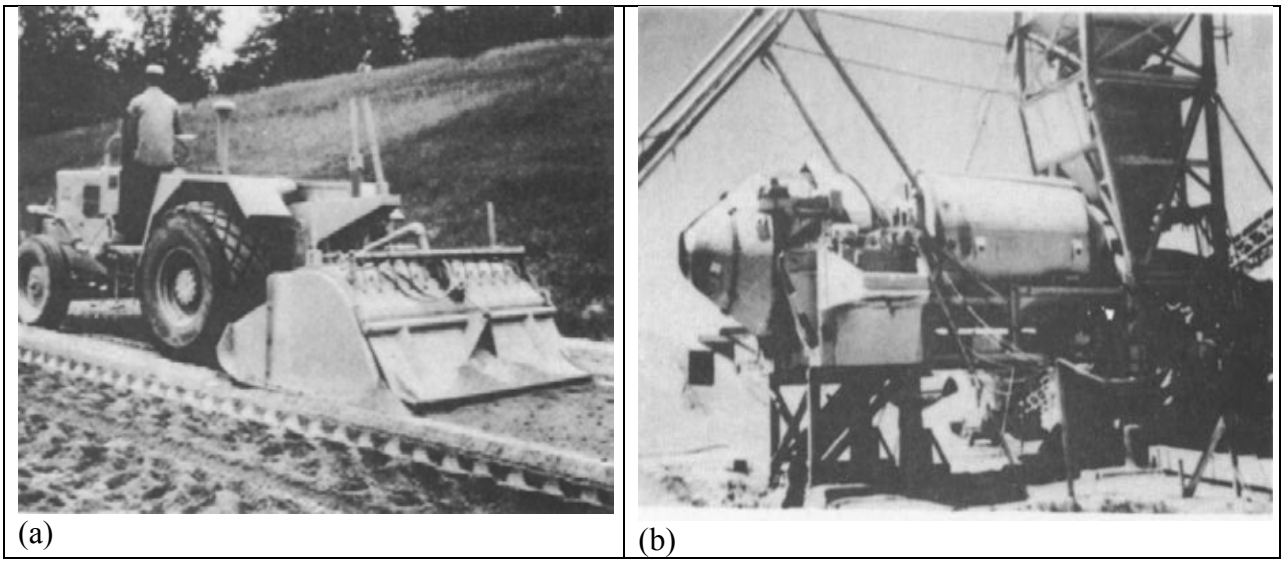

Fig. 8. Methods for cement stabilization at construction site (a) direct mixing (b) mix plant (Photos courtesy of US Army Technical Manual [13]).

modified proctor tests is shown on Fig. 4. A summary of geotechnical parameters of soil deduced from the analysis of different laboratory tests are summarized in Table 2.

The soil sample is classified as "SP – Poorly Graded Fine Sand" based on the unified soil classification system [21]. Soil is classified as A-3(0) using AASHTO soil classification system [22]. A-3 soils can be rated as excellent to good subgrade material in areas not affected by excessive environmental changes, water of flood and rainfall inundation [23]. Further, A-3 material is preferred to be used as subgrade by designers in the areas having dry moisture deficit climate, deep water table, good external drainage and no permeability inversion [24]. However, in case of using A-3 soil material as subgrade without stabilization in environmental variant conditions and water inundation areas its performance is capricious [25]. Therefore, A-3 soil materials when used in areas having inversion of permeability due to floods or rains than it need to be stabilized by additives. Cement and bitumen are most suitable additives for improving the strength and durability properties of A-3 subgrade soils [26]. Generally, soils are stabilized for highways subgrade to achieve unconfined compressive strength (UCS) of 150 kPa more than the UCS of soils originally anticipated without the use of additive [26].

For stabilization of A-3 soil, an initial estimated cement content of 7, 8 and 9 % was employed [10]. The samples for unconfined compression test was reconstituted at density and moisture determined from modified proctor test (Table 2). Fig. 5 shows the unconfined compressive strength variation with age of curing in stabilized samples. It is eminent from Fig. 5 that the soil unconfined compressive strength with stabilization additive increased drastically and reached to an average value of more than 1200 kPa against curing time of 28 days. The strength values observed in cement stabilized subgrade samples of the samples are comparable with strength values of the same soils reported in literature [27].

Fig. 6 shows test results of A3 soil sample stabilized using MC30 and RC70 cut back bitumen samples. The 30 and 60 represented the minimum kinematic viscosity of the cutback determined using Saybolt Furol Viscometer [28]. 7 to 9 % bitumen content by weight of dry aggregates was obtained by keeping kerosene oil from 25 to 40 % and using equation 1 [13]. The A3 soil stabilized with MC30 and RC70 were remolded at density determined from modified proctor test. On the same density the A3 soil stabilized with 7 % MC30 and RC70 showed strength less than threshold of desired unconfined compressive strength. However, both 8 and 9 % MC30 and RC70 samples showed reasonable strength above threshold level. The soil samples stabilized with MC30 showed lesser distinctive plastic phase than samples stabilized with RC70 during unconfined compressive strength. However, both MC30 and RC70 samples showed distinctive elastic phase.

In recent years, the use of different non-traditional additives like waste fiber materials for the stabilization of soils is an area of interest around the globe. The random size polythene and polyester fibers can be used effectively for stabilization of sandy soils [29]. Polythene bags and polyester packing material from a local waste lot was collected. Both materials were manually shredded in random sizes approximately with diameter range between 0.1 to 0.2 mm and length ranges from 22-26 mm. 1 – 2 % polythene and polyester fibers were added by weight of dry soil during remolding of samples at modified proctor density and optimum moisture content [30]. Fig. 7 shows results of unconfined compressive strength of soils stabilized using polyester and polythene fibers. It is eminent that both fibers enhance the strength of the A3 soil drastically, hence both has strong potential to be used as alternate stabilization material for A3 type soils. However, amount of polyester and polythene should be

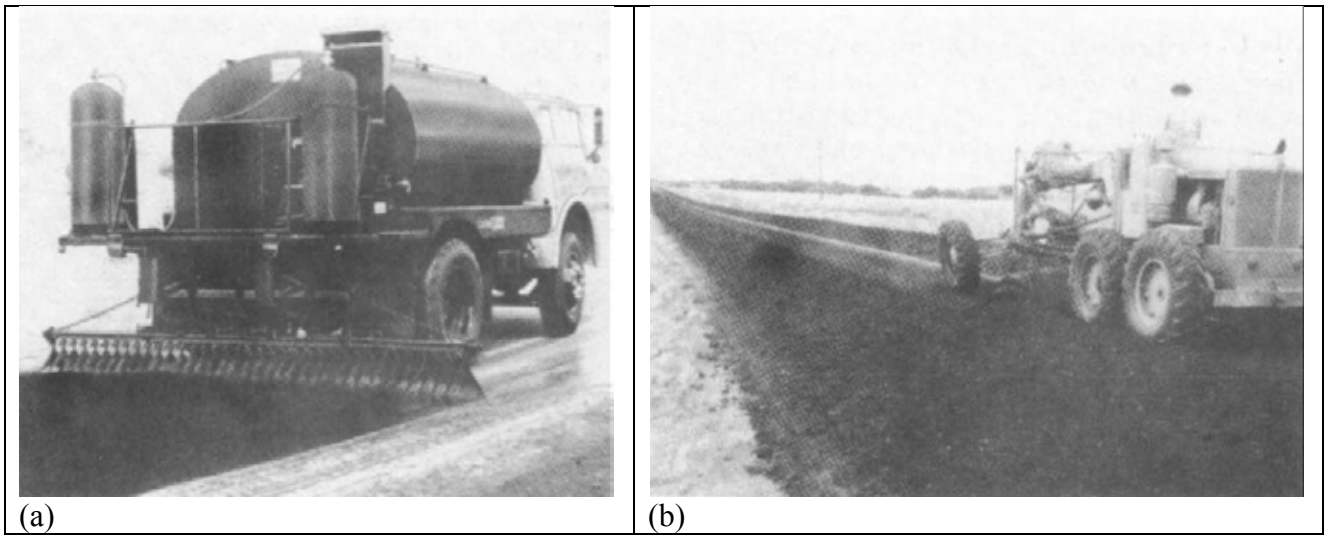

Fig. 9. Steps for bitumen stabilization at construction site (a) Bitumen spreading (b) Bitumen mixing with soil (Photos courtesy of US Army Technical Manual [13]).

Fig. 10. Proposed steps for polythene/polyester fibers stabilization at construction site: (a) Fibers shredding; (b) Fibers spreading; (c) Fibers mixing with soils (Photos courtesy of Google Images, http://www.google.com).

greater than 1.5 % to achieve the minimum threshold unconfined compressive strength under soaked conditions.

Cement stabilization at the construction site is usually carried out either by direct mixing method or by mix plant method (Fig. 8). Bitumen stabilization at the site is carried out by direct mixing method (Fig. 9). More laboratory experimentation literature is available about the stabilization of subgrade soils using polythene and polyester fibers. However, to date insignificant literature is available about its construction methodology. In this research brief cost effective construction methodology of polythene / polyester fibers stabilized soils is described. Waste plotythene/polyester can be shredded in desired dimensions using automatic shredders (Fig. 10 a). The shredded materials are than spread using hydraulic jack trolley system (Fig. 10 b). The fibers are than thoroughly mixed with subgrade soil using motor graders (Fig. 10 c). To evaluate the cost effectiveness of these three stabilization methods, an analysis of rates for their construction has been established. Fig. 11 shows the comparison of rates between different stabilization methods using database of five districts of Pakistan having sufficient A3 soils deposits in it and around its surrounding. A3 unstabilized soils rates database has been taken from latest

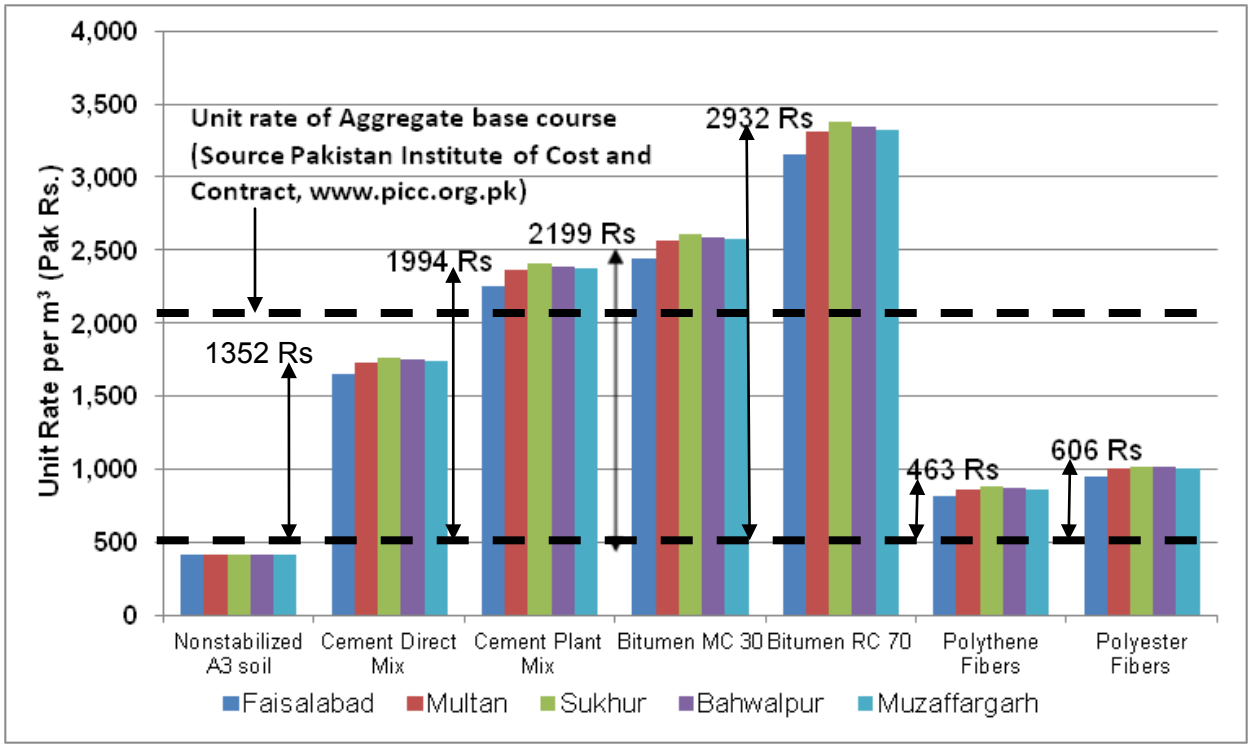

Fig. 11. Cost comparison of different stabilization methods in five major districts of Pakistan.

composite items rates for different districts of Pakistan published by Pakistan Institute of Cost and Contracts for August 2013. In analysis of cement direct mix rate cost of material (cement for 8 % optimum, A3 soil, and water), machinery (spreader, compactor, water tanker and grader) and labor cost of field activities has been used. For cement plant mix rate analysis the cost of material (cement for 8 % optimum, A3 soil, and water), cost of machinery (cement plant, transit mixer, pump/hydraulic dump, compactor, water tanker and motor grader) along with allied field labor has been employed. The analysis of rates for bitumen stabilization soils has been carried out by using cost of materials (kerosene, MC-30/RC-70, A3 soil and water), cost of machinery (sprayer/spreader, grader, water tanker, and compactor) and relevant field labor. The rates for waste fibers stabilized soils has been analyzed by considering cost of materials (polythene, polyester, A3 soil, water), cost of machinery (shredder, spreader, compactor and water tanker) and associated labor. It is eminent from Fig. 11 that both waste materials showed minimum unit cost in comparison to other stabilization additives i.e. cement, bitumen. Extraordinary rise in petroleum products (kerosene and bitumen) in recent years around the globe makes bitumen stabilization relatively uneconomical (Unit cost even more than aggregate base course). The cost of plant mix cement stabilization is also high. The option of cement stabilization using direct mix method is seems to be relatively more comparable option in term of economy as well as strength with other stabilization options. Insignificant change has been observed in the composite unit rates of different individual stabilization methods in five major districts of Pakistan.

4. CONCLUSIONS

Pakistan has number of important highways/road projects whose design and construction is in pipeline now like M4 (Faisalabad Multan Motorway Section), M5 (Multan Rajanpur Motorway Section), M6 (Rajanpur to Ratodero

Section), M7 (Ratodero to Liyari Section), M8 (Ratodero to Gawadar Section), M9 (Hyderabad Karachi Section). Most of passages of these projects have been significantly affected by the floods and rain inundation in recent years. Further, the surroundings of most of these projects have significant deposits of A3 soil materials that can be used after stabilization as subgrade in its construction. This research is going to give a comprehensive elaboration of different stabilization methods of A3 soils to be used for prospective projects in Pakistan based on strength characteristics, methodology of construction and economy. Following specific conclusions can be drawn from above findings:

1. The cement stabilized A3 soils has merit over other stabilizations in strength therefore it can be used with confidence as subgrade on new highways effected by environmental variations and water inundation areas subjected to any kind of traffic loading (light, medium or high).
2. The A3 soils stabilized with bitumen MC30 and RC70 are less cost effective than cement stabilization. The strength of bitumen stabilization is in lower threshold and cement stabilization is in higher threshold of design ranges. Therefore, bitumen stabilized soils should be preferred as subgrade on new roads effected due to environmental variations and water subjected to relatively light to medium traffic loading. Further, to maintain quality control and environmental protection of bitumen stabilization during field operations is also complex. Hence, its use for highways subjected to relatively heavy traffic loading is restricted.
3. A3 soils stabilized with waste polythene and polyester fibers do have reasonable potential to act as alternate of bitumen stabilization in term of strength. However, creep studies of these organic materials in the mix under traffic loading are needed to be investigated.
4. A3 subgrade soils stabilized by cement, bitumen or polythene/polyester fibers have its application horizon in both technologies of roads construction (surface treatment and plant pemix) in Pakistan.
5. Polythene bags and polyester packing are two most abundantly found waste materials in Pakistan. The treatments of these materials are costly to make it environment friendly. By using these materials for the soil stabilization can be a good mode of its disposal for the protection of environment.

Based on the findings of this laboratory-based research it is recommended to construct trial sections of the subgrade in the field and directly evaluate stabilization characteristics under different loading and inundation conditions. This will give further confidence to the findings of this research.

5. ACKNOWLEDGEMENTS

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Research Article

Design and Development of a Data Logger Based on IEEE 802.15.4/ZigBee and GSM

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Abstract: The Data Logger (DL) is a special device which is designed to accomplish a common task that is to collect data in a targeted area. Some of the DLs have onboard integrated sensors while some collect data using the wireless sensor nodes WSNs. According to the literature some of the proposed DLs are expensive and slow in operation while some do not fulfill all the application requirements i.e. long and short range data logging. Thus a cost efficient, fast and a wireless DLs are the need of a day. In this paper a customized wireless DL is designed, which is cost efficient, fast and can perform in a wide and short range. The designed data logger is based on IEEE 802.15.4 and GSM Technology and use a 32bit microcontroller as a central processing unit. The designed DL is beneficial for the researchers and application developers in data logging and monitoring of environment, weather and road traffic etc.

Keywords: GSM, data logger, TCP/IP, PIC microcontroller, Zigbee

1. INTRODUCTION

Data recording and data analysis play a vital role in the development of new innovations and the prediction of high probable future events. An application such as recording road traffic data, climate change, pollution monitoring, environmental data collection, energy monitoring are now gaining a worldwide attention. A data logger is a device which is used to record and monitor data of a certain process in a specific location.

Using DLs it is now become possible to record and monitor data such as the movements of individual sharks, whales, sea turtles and jellyfish in the bottom of a sea [1]. The data monitoring and recoding period can be as short as several milliseconds such as monitoring a signal propagation time from source to destination or measurement of the I-V characterization of an electronic device, hence the DL must be very fast that it can monitor and record the transient dynamics of a process [2]. The data logging periods of some processes are very long like monitoring and recoding the environmental parameters, collecting road traffic data, the availability of wind and solar energy, hence the DL must be energy and data efficient such that it can perform for a long time with a battery backup and can store a large amount of data [3]. It is justified that in designing of an embedded systems minimum cost, high speed and maximum power efficiency in a design are primary concern. The

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main contribution of this paper is to showcase a DL which is cost and energy efficient and can also perform as a wide and short range wireless data logger.

The development of the proposed data logger is being done in the following sections: Section I gives an introduction, In section 2 some related literature to the proposed work proposed is presented along with prior work. In section 3, The operation of the DL and wireless sensor network and TCP/IP communication of the DL is explored. In section 4, Circuit implementation of the designed DL is presented. Section 5 includes experimentation and testing of the designed DL. Finally, the conclusions and further work are given in section 6.

2. PRIOR WORK

A low cost tele-health monitoring system which is based on a microcontroller and computer based software for an on line data monitoring and recoding is presented in [4]. While a field programmable gate array based super conductor characteristics monitoring system is designed in [2]. A general purpose low- cost, low power consumption, flexible sensor attachment with an optional WI-FI facility and XML-based spatial-temporal DL is presented in [5] and a microcontroller based low cost DLs integrated with humidity or temperature sensors having extended flash memory or SD card was designed in [6-11].

The DLs presented in [2-5] are few expensive and are application specific, while the DL proposed in [5-10] are based on low speed 8-bit microcontrollers and lakes the IEEE802.15.4/Zigbee interfacing facility, which is very essential for wireless data logging in modern systems [12] [13] while in the proposed DL it is included.

Minimum cost, less energy consumption and high speed have great importance in the embedded market, hence design- in an embedded system like a DL minimum cost, minimum energy consumption and high processing speed are kept in the first priorities, In the proposed DL maximum speed and minimum cost are achieved by using low cost 32 bit microcontrollers i.e. PIC32MX250F128B and jennic JN5148. The use of portable DLs and remote data logging is gaining importance in many applications as in [14-17], hence the designed DL is enhanced by adding Internet access through TCP/IP using Global System for Mobile (GSM).

3. THE PROPOSED DATA LOGGER

The PIC32, JN5148 and GSM module are the main components in the designed DL, PIC32 microcontroller acting as a control unit of the DL. Data from wireless sensor nodes is received by JN5148, PIC32 takes data from the JN5148 through UART2, after the data is successfully received, if GSM services are not available data is than saved on EEPROM and if GSM services are available the data is transmitted on a TCP/IP.

In order to explore the working of the designed DL its data flow and interfacing with a data base and some wireless sensor nodes is presented in Fig. 1.

The designing of the DL is divided in three sections: in the first section the integration of the main control unit i.e. PIC32MX250F128B within the system and its advantages are described, in the second section interfacing of GSM-TCP/IP and JN5148-IEEE 802.15.4/Zigbee is discussed. In III section the block diagram and schematic of the designed DL are presented.

3.1 The Central Processing Unit PIC32

The PIC32MX250f128b is chosen as a centralized control unit for the DL due to the following reasons:

- To achieve the maximum processing speed the microchip PIC32 is selected which is a 32 bit microcontroller with MIPS4000 core and maximum clock speed of 80Mhz, 512 KB programming memory and 32KB RAM [18]

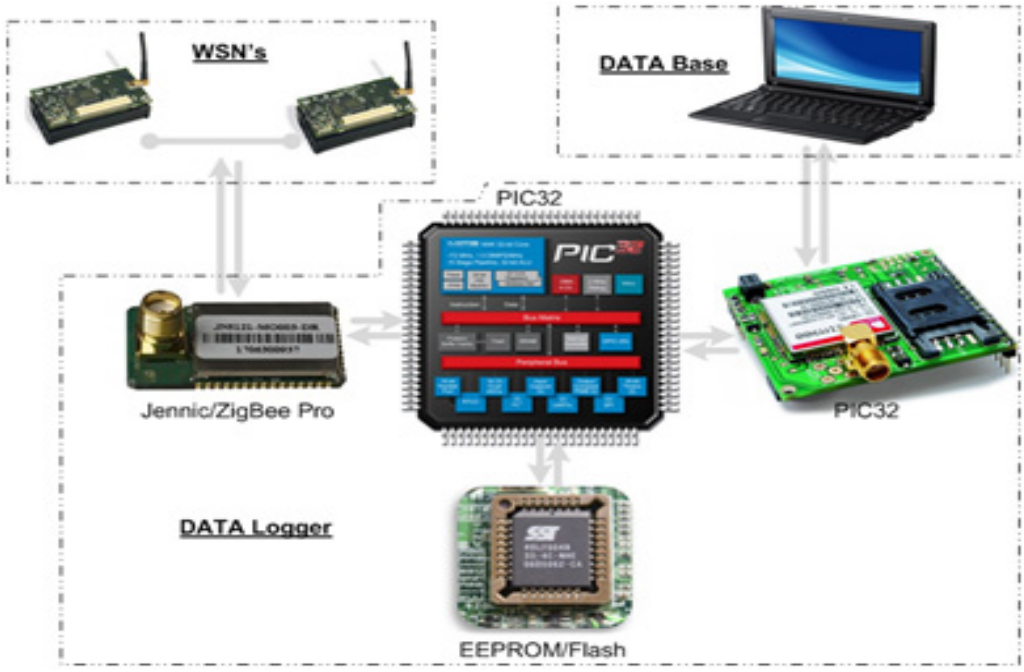

Fig. 1. Data flow diagram of the designed DL and interfacing with database and wireless sensor nodes.

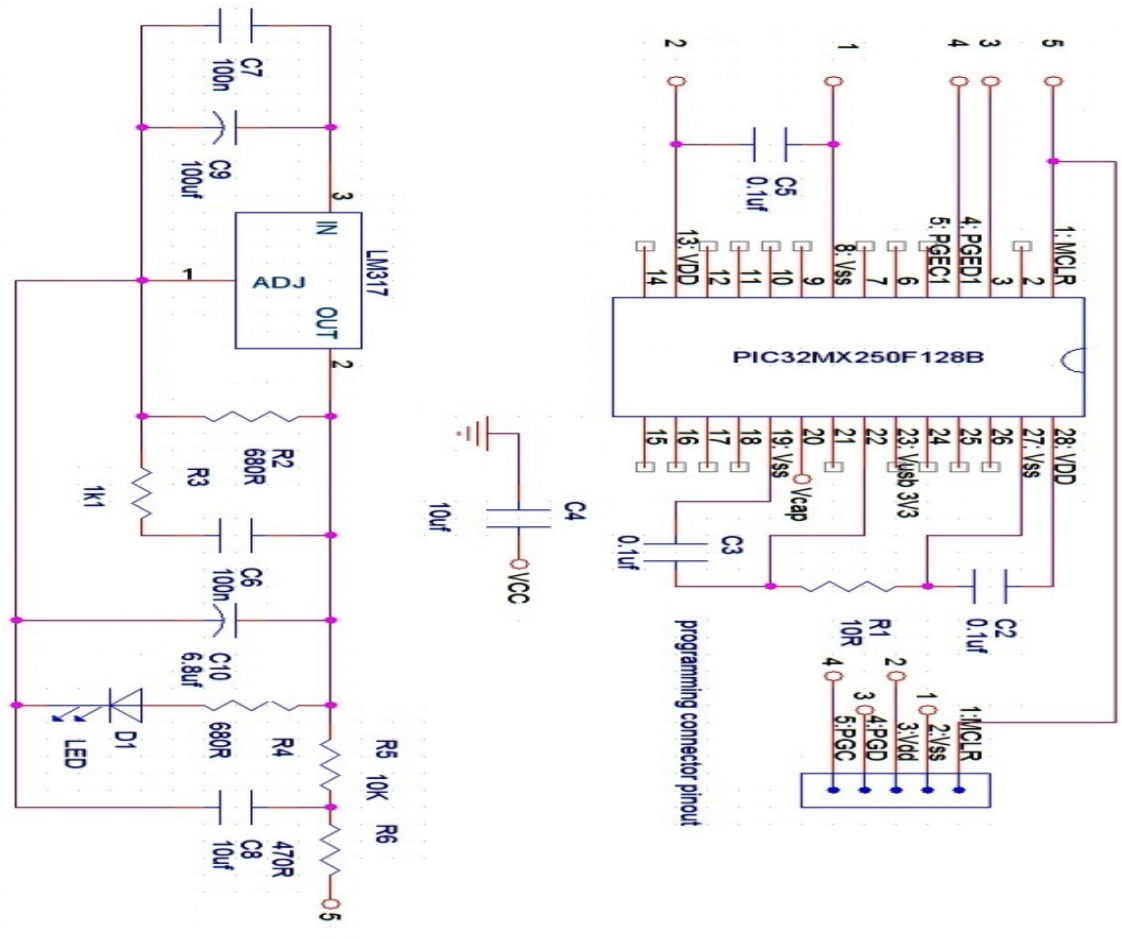

Fig. 2. The Basic PIC32MX2xxFxxxB circuitry with a programming header interface.

and is relatively four times faster than the8bit microcontrollers which are used in [5-10].

- As the minimum cost of the designed DL is required, PIC32MX250f128b is used in the system which is a cost effective solution and all mostly it costs less than 3$ per chip.
- PIC32MX250f128B is an energy efficient solution, normally it operates at 2.3 V to 3.6 V DC and consumes less than 0.5 mA/Mhz.
- PIC32MX250F128B is DIP-SOC and can easily be integrated on any circuit board.
- To make the designedDL user friendly PIC32 is selected because it supports on board and Graphical User Interface (GUI) based programming, hence one who has limited knowledge about C language can easily implement the complicated algorithms over PIC32 using MATLAB Simulink blockset GUI [19].

The schematic and basic circuit of PIC32MX250F128B is given in Fig.2, while the technical data about PIC32 microcontroller family, which is more important for designing a data logger which is given below:

- MIPS 4000 core, maximum clock speed 80 MHz
- Maximum of 512 KB program memory, 32 KB RAM
- Up to 85 I/O pins and two I2C buses.

3.2 IEEE 802.15.4/ZigBee Implementations

To communicate with wireless sensor nodes in the designed DL the IEEE802.15.4 based Zigbee JN5148 M003 wireless microcontroller is used. The ZigBee is a wireless data communication and networking protocol which is based on IEEE 802.15.4 standard and is primarily designed because of the following reasons as given in [20-21].

- Zigbee is a Low power wireless short range data communication and networking solution.
- Zigbee is a self-organizing wireless data communication and networking option.
- Zigbee based devices are cost effective, highly reliable, short latency, has low rate and has high capacity as compared with Bluetooth, IrDA, Wi-Fi and GPRS

ZigBee networks can be divided into four layers, in bottom of ZigBee protocol stack we have physical layer (PHL), after PHL media access control layer (MAC) and then network layer (NWK) and application layer (APL), each layer provides data to its upper and management services. More over ZigBee application layer consists of sub-layer (APS), ZigBee device object (ZDO) and manufacturer-defined application objects.

The network based on ZigBee protocol is composed of three kinds of i.e. sensors nodes (End-Device), routing node (Router) and a pool node (Coordinator). The coordinators act as a parent while router and end devices act as a childes. To organize ZigBee network there must be at least one coordinate is it is the responsible of a coordinator in a network to initialization and maintain a network. End devices acts as a sensor nodes usually they collects data from sensors. The function of Router is to rout information in between coordinator and end devices. ZigBee supports Star network (star), tree network (tree) and the mesh network (mesh) topology, the topology is implemented on the bases of application [21].

In the designed DL the IEEE802.15.4 based Zigbee JN5148M003 wireless microcontroller is used, which only support all network topologies. In the proposed DL before doing any wireless sensors data acquisition operation the JN5148 M003 must be programmed as a coordinator.

4. TCP/IP IMPLEMENTATION

The SIM900 GSM module is used to connect the data logger with remote data base through TCP/IP. There are two modes of connection for SIM900 TCP/IP application i.e. single connection and Multi connection. In single connection mode, SIM900 can work at both transparent mode and non-transparent mode and under these two

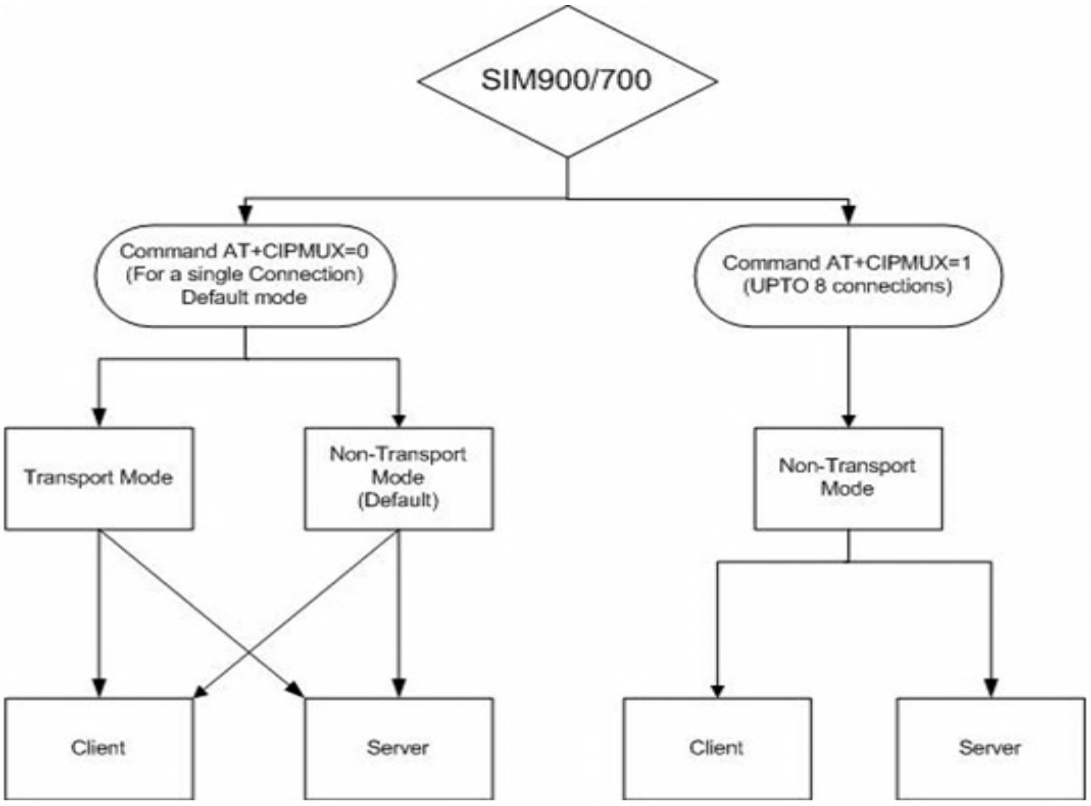

Fig. 3. GSM Modem-SIM900-TCP/IP configuration.

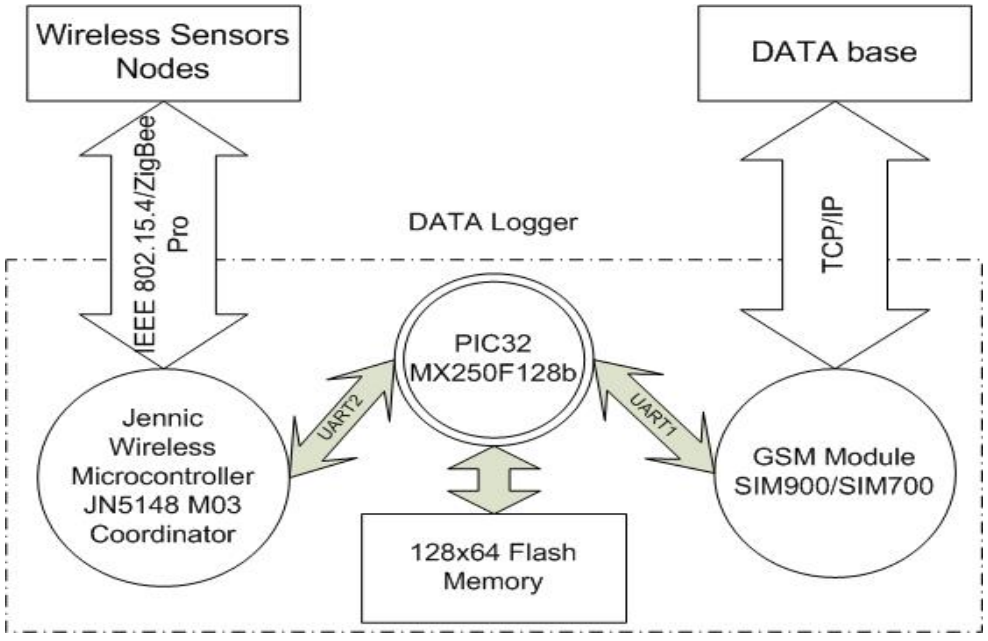

Fig. 4. Working flow diagram of the proposed data logger.

transmission modes, SIM900 can be configured as either TCP/UDP client or TCP server. When in multi connection mode, SIM900 only can work at non-transparent mode. In this mode, SIM900 can work as an absolute TCP/UDP client, which can establish 8 connections in total. In this mode, it also can be configured as one TCP server, which allows 7 TCP/UDP clients to connect in and the TCP server also can act as a client, establishing seven connections to one remote server. The structure of the TCP/IP application is given in Fig. 3.

5. THE SYSTEM DESCRIPTION AND WORKING

The overall working of the data logger is presented in a form of a block diagram in Fig. 4. A wireless sensor network is composed of a coordinator, end device and router. Coordinators act like parents and end node and routing devices acts like childes during a network formation. In any wireless sensor network at least one coordinator is required, in the designed data logger the (Jennic wireless microcontroller JN5148 M003) which is acting as a coordinator and is responsible to collect data from the deployed wireless sensor nodes. The main control unit that is PIC32 has two UARTs one is used to communicate with Jennic microcontroller while other is used to communicate with the GSM module. The coordinator transfer received data serially to the main control unit that is PIC32. As the data is received on PIC32, the control unit checks the availability of GSM services and if GSM services are available the data is transmitted to the data base and online monitoring software, if GSM services are not available the collected sensor data is than stored on the flash and at the same time at regular intervals the control is also checking the GSM services, as soon the GSM services appeared the data stored on the flash is transferred to the data base via TCP/IP. This whole operation of data exchange and storage is commanded by the control unit, the explanation of the operations performed by the control unit is given Fig. 5 in form of a flow chart.

6. HARDWARE FABRICATION

A prototype of the proposed DL is fabricated initially to test the device. A PCB of the proposed DL is designed is a ALTIUM designer software, however no any electronic simulator is available in the market which can simulate the PIC32, Jennic MCU and GSM-SIM900 device there for each and every device is tested and evaluated in real time. To test the data logger each device is programed and tested separately on a computer UART and finally the end product is developed. A photograph of the prototype of the designed data logger is given in Fig. 6. The DL can communicate with a remote data base through a TCP/IP in a case when the hardware is configured as an ”A” of Fig. 6, while using the DL as in ”B” of Fig. 6 the device only stores data on the flash.

7. SOFTWARE DESIGNING

Monitoring and recoding of meteorological, geographical and transportation information etc. have a great importance in research and development, usually monitoring and recoding of meteorological, geographical and transportation information is accomplished through the data loggers. In literature review it is analyzed that minimum cost, minimum energy consumption, wireless facility, portability and maximum processing speed of a data loggers is the need of a day. The work in this paper was carried out to design a data logger which is a cost efficient, energy efficient, wireless, portable and high processing speed than the data loggers designed in the literatures. Achieving minimum cost, maximum speed and low energy consumption of the proposed design was become possible by introducing the PIC32 and Jennic JN5148 microcontrollers.

The designed DL is wireless and is compatible with IEEE 802.15.4, GSM and TCP/IP and it is also able to perform in both off line and on line modes in off line mode the designed data logger stores data on its flash while in on line mode the data logger send data to the data base.

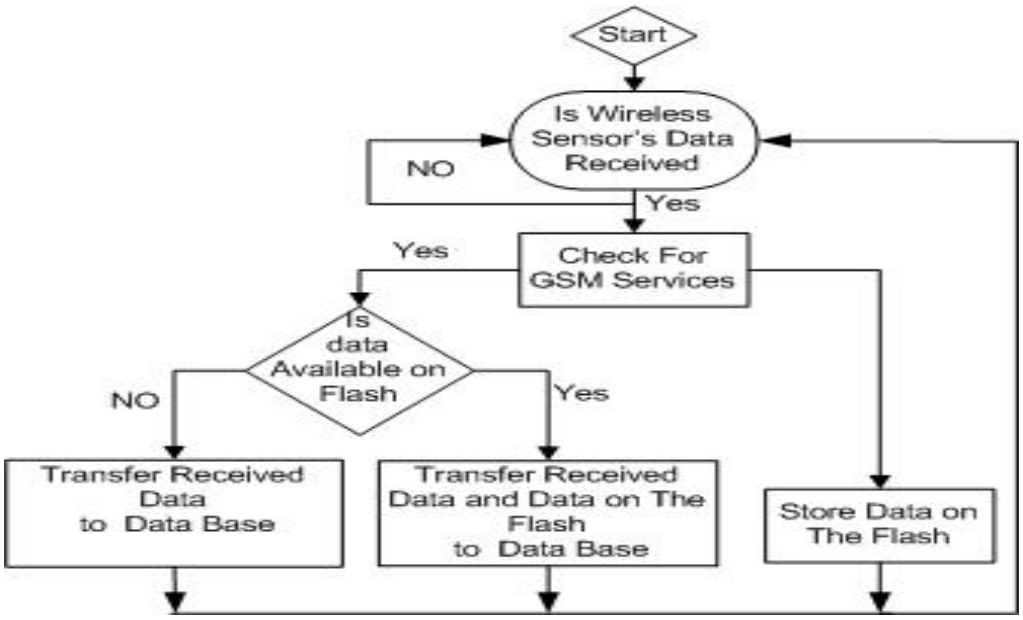

Fig. 5. Operations and functions performed by the control unit.

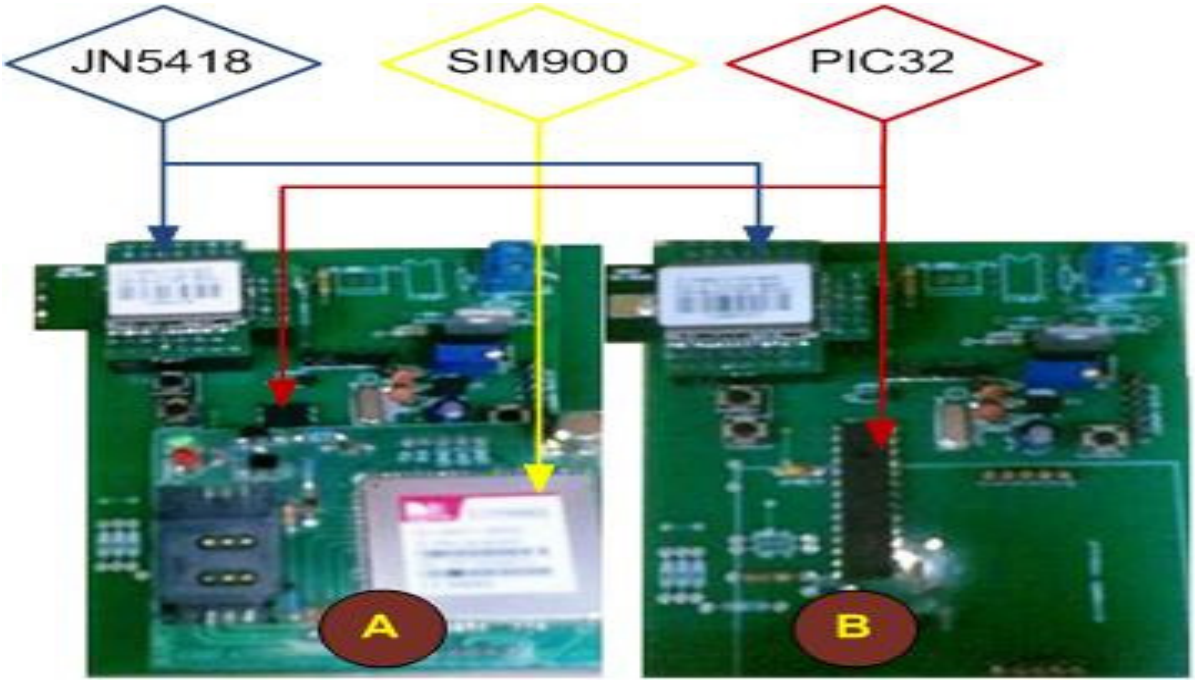

Fig. 6. In Figure "B" the designed DL board is shown without a GSM module while in Figure "A" the GSM module is mounted over the DL board.

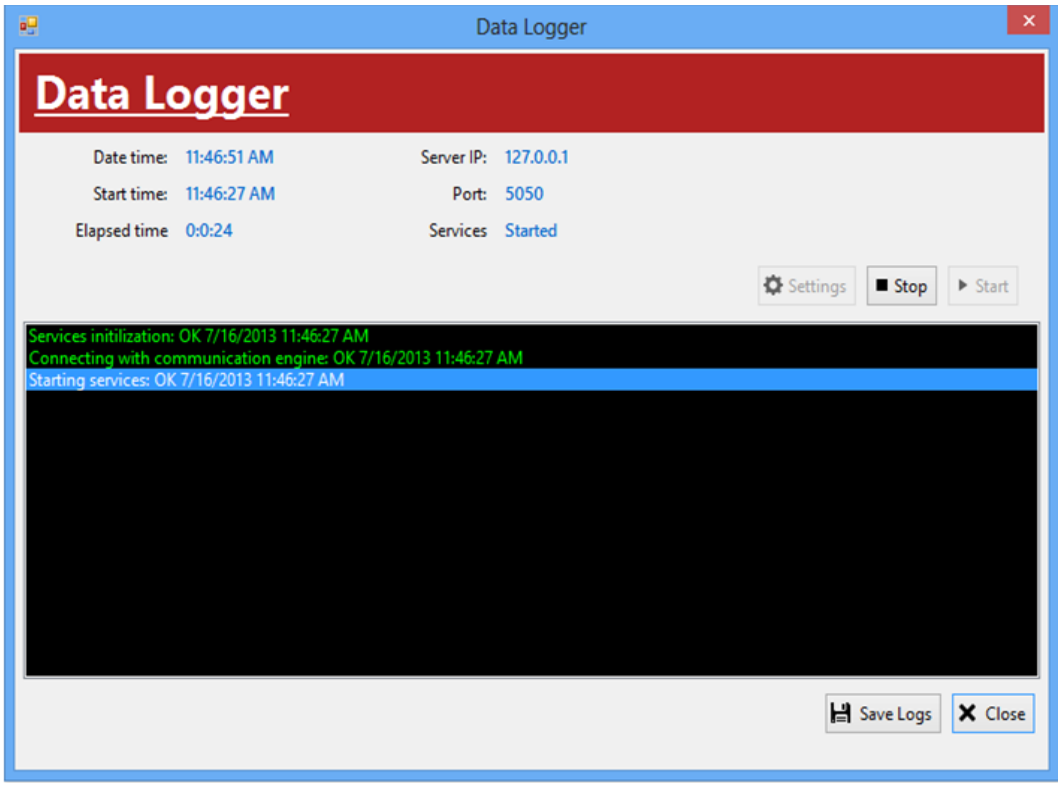

Fig. 7. A screenshot of the data logger software for TCP/IPC on figuration and communication.

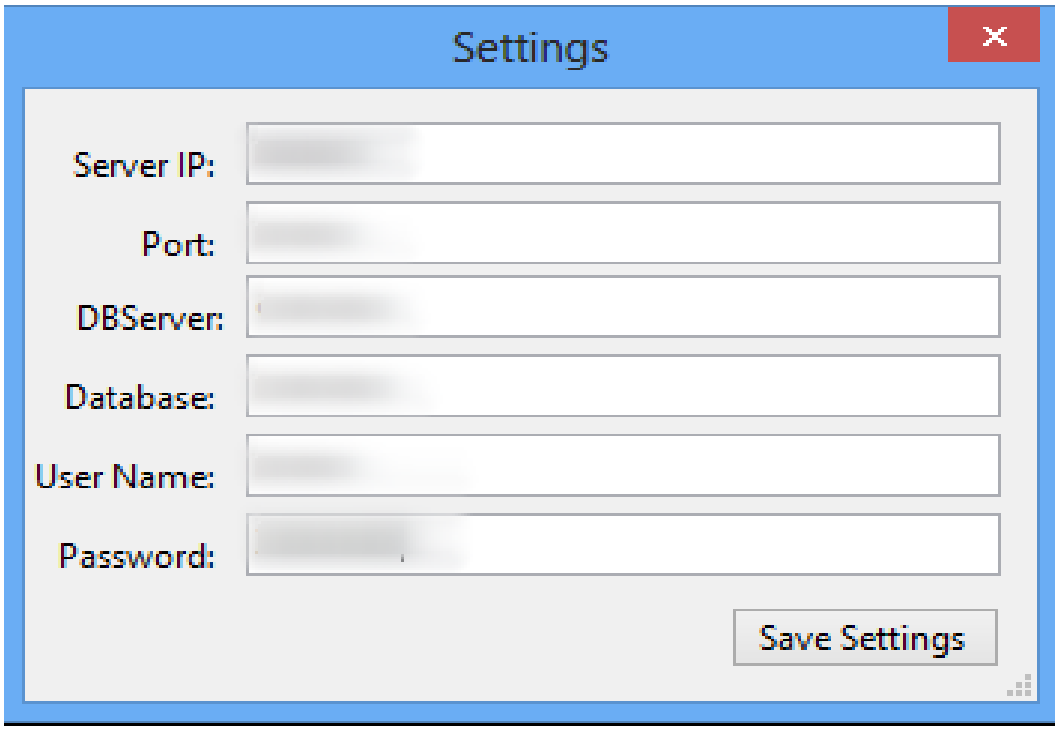

Fig. 8. A screenshot of setting window of the designed software.

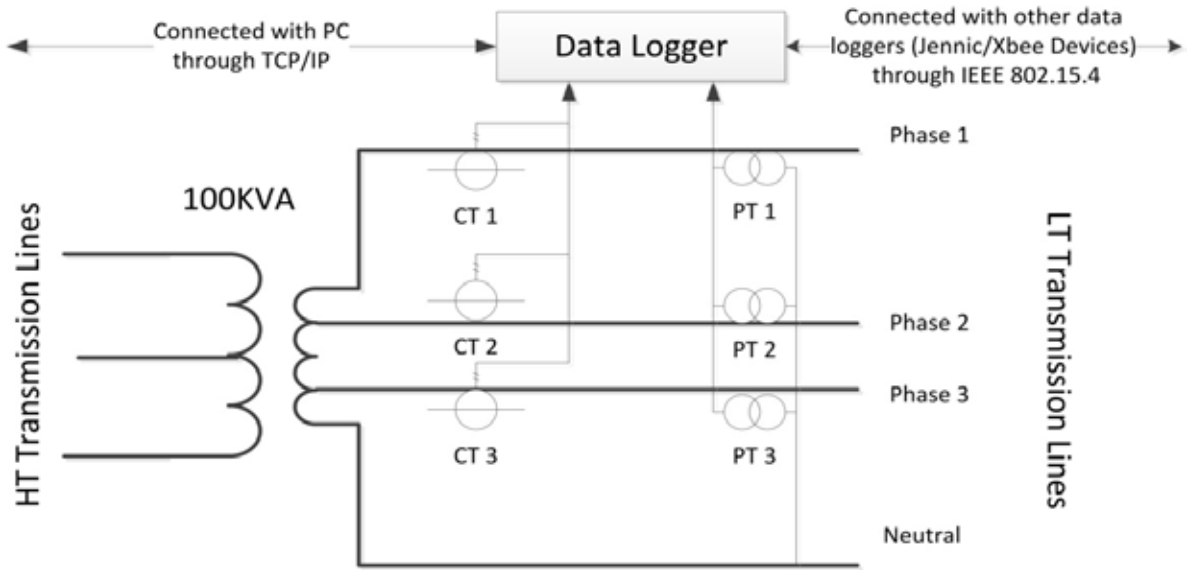

Fig. 9. Schematic diagram of DL operation.

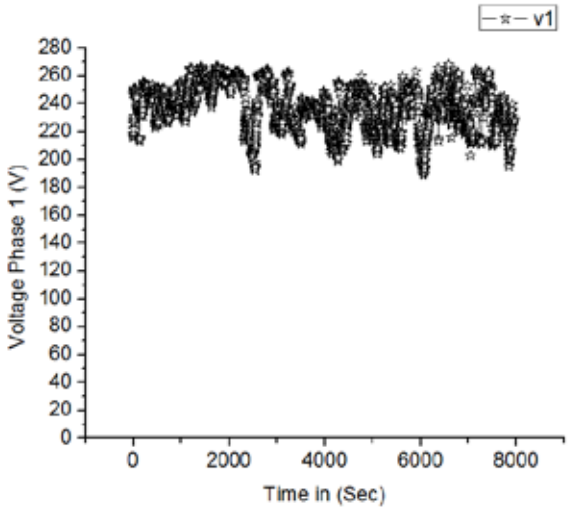

Fig. 10. Voltage of Phase 1 of the transformer.

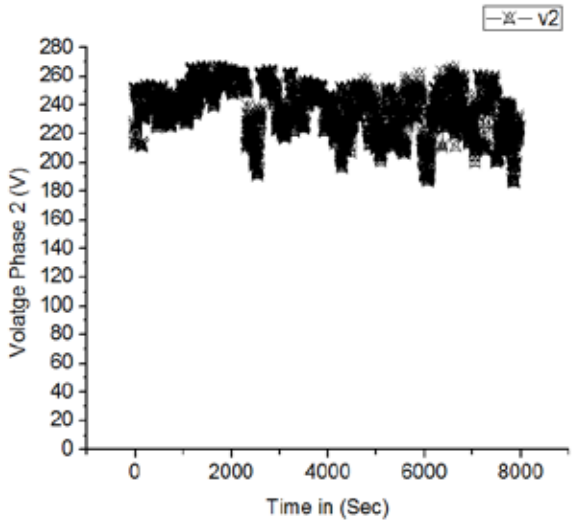

Fig. 11. Voltage of Phase 1 of the transformer.

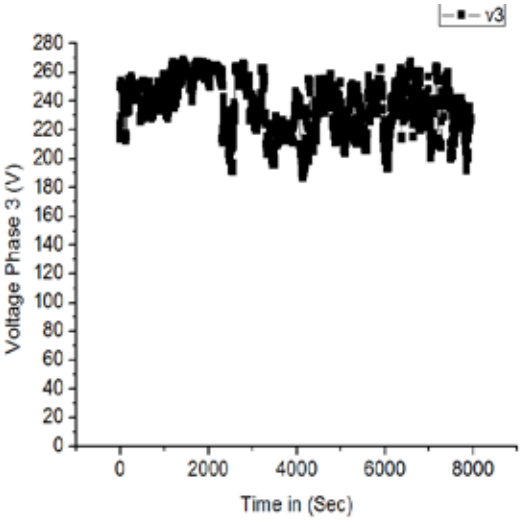

Fig. 12. Voltage of Phase 1 of the transformer.

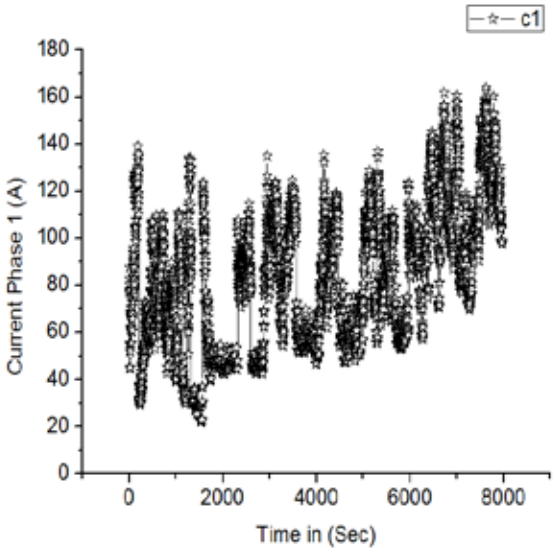

Fig. 13. Voltage of Phase 1 of the transformer.

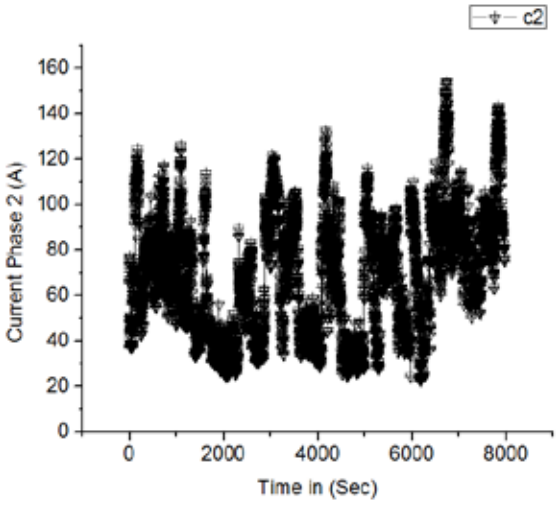

Fig. 14. Current of Phase 1 of the transformer.

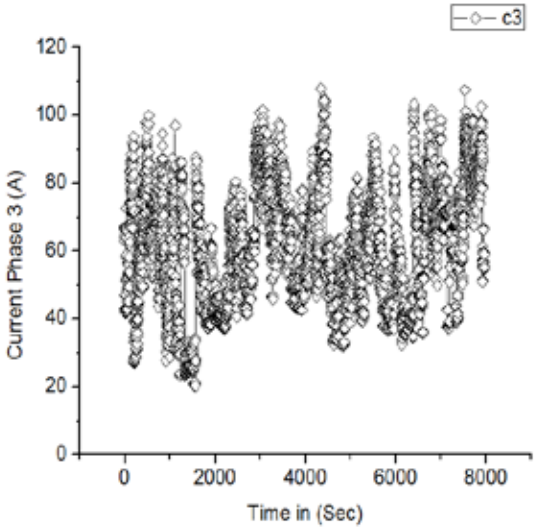

Fig. 15. Current of Phase 1 of the transformer.

Some of the screen shorts of the designed data logger are given in Fig.7&8, whichproves its validity. The current printed circuit board PCB of the designed data logger is a single layer in future one can more miniaturizes the size of the designed data logger by implementing it on a two or more layer PCB. The power supply of the designed data logger is not rechargeable hence in future it is needed to design a power supply for the designed data logger which is rechargeable from some renewable resource such that one can easily use it in remote applications.

8. DATA LOGGER IMPLEMENATIOAN AND RESULTS

The designed data logger is connected with a 100KVA transformer in the way as shown in the Fig. 9. The current and voltage of each phase of the transformer was monitored for 8000 Sec (Iteration time 1 Sec). The collected data of the voltage and current is transferred to Computer using TCP/IP module from DL. The voltage data of each phase of transformer, i.e., V1, V2 and V3 are shown in Fig. 10, Fig. 11 and Fig. 12, respectively. Also the current data of each phase of transformer, i.e., I1, I2 and I3 are presented in Fig. 13, Fig.14 and Fig. 15, respectively.

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Research Article

Task Distribution Mechanism for Effective Collaboration in Virtual Environments

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Abstract: Collaborative Virtual Environments (CVEs) are computer generated worlds where two or more users can simultaneously interact with synthetic objects to perform a task. User performance is one of the main issues caused by either loose coordination, less awareness or communication among collaborating users. In this paper, a new model for task distribution is proposed, in which task distribution strategy among multiple users in CVEs is defined. The model assigns the task to collaborating users in CVEs either on static or dynamic basis. In static distribution there exists loose dependency and requires less communication during task realization whereas in dynamic distribution users are more dependent on each other and thus require more communication. In order to study the effect of static and dynamic task distribution strategies on user's performance in CVEs, a collaborative virtual environment is developed where twenty four (24) teams (each consists of two users) perform a task in collaboration under both strategies (static and dynamic). Results reveal that static distribution is more effective and increases users' performance in CVEs. The outcome of this work will help the development of effective CVEs in the field of virtual assembly, repair, education and entertainment.

Keywords: - 3D interaction, virtual reality, awareness, collaborative virtual environment, user performance.

1. INTRODUCTION

The advent of powerful personnel computers with realistic 3D graphics capabilities and real time processing of 3D trackers data have caused the immersions of virtual environment where two or more user can co-exist and perform a task,. These environments are called Collaborative Virtual Environments (CVEs) [1]. Some of the CVEs application are education, assembly, entertainment, engineering design, military training, tele-presence and virtual surgery [2]. More advanced CVEs, which support complex, real time and haptic collaboration have been suggested for numerous applications, mainly in the area of training [3-5]. Avatars (ball, simple virtual hand, sphere, circles and humanoid avatars etc.), Data in the form of audio, video and textual, are the main requirements for CVEs. Audio data is used in teleconferencing application while video data is used in video conferencing application. The audio, visual and haptic awareness virtual modalities are used for better communication and user's assistance in CVE to increase user performance [7, 8].

In CVEs interaction with objects may take synchronous or asynchronous form [6]. In synchronous type interaction concurrent manipulation of separate or the same attributes of

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an object are carried out. For example one person holds an object and the other paints it or suppose two or many peoples displace or lift a weighty object together. While in asynchronous type of interaction in CVE the sequential manipulation will be carried out with the distinct or with same attributes of the objects. For example one person changes the object position and another person changes it further. To perform collaborative task in CVEs either synchronously or asynchronously awareness is important to achieve better performance. The awareness concept in CVEs as defined by [1] mainly concerns the presence and activities of other users. Awareness is the knowledge of a user about the actions, intensions and status of other users in collaborative virtual environment. The awareness measures the degree, nature or quality of interaction between two objects or users [9]. Communication among the users is an essential factor for better awareness. The communication may be verbal such as audio or nonverbal such as visual, gestures based, pointing to or even facial expressions [10].

Various models have been presented by Benford and Fahlen [11], Sandor et al. [12], Ullah et al. [19], Otmane et al. [18] and Rodden et al. [14] to increase user performance in collaborative virtual environments. In CVEs as multiple users are involved for task execution. So either all the users will work on a single task or the task is divided into subtasks and users work on it in groups. Very little work has been done in literature on how to distribute the task among groups and subtasks among the members of a particular group? In this paper we present a novel task distribution model according to which task assignment to collaborative users can be made either statically or dynamically. In addition, the effect of each task distribution type (static and dynamic) on user's performance is studied in a collaborative virtual environment. Similarly the communication coordination and awareness requirements of the static and dynamic distribution are also investigated. Our investigation will help in the development of effective CVEs (ensuring increased user performance) in the field of virtual assembly and repair, virtual environment for education and entertainment and tele-operation systems.

This section is followed by the related work. In Section 3 the proposed model is described. In Section 4 the experiments and their results are shown. In section 5 conclusion and future work are given.

2. RELATED WORK

The best-known work performed for the management of interactions in the CVEs is the spatial model of interactions proposed by Benford and Fahlen in 1993 [11]. Basically it is used to control data transmission in CVEs. The main theme of this model is to use the space properties as a base to start and allow interaction and communication among the objects of CVEs. In this model the virtual space is breakdown to metric spaces, to measure different objects directions and positions. For orientations and positions settings, objects of the CVEs have the capability to change their interaction and communication. Interaction between objects occur via combination of media transmission like text or visual, audio and video through specific interfaces. According to Benford model, interaction between two objects becomes possible whenever their auras collide or overlap. In this model only modalities are described to increase the user awareness for better performance. The spatial model has limited support for contextual factors in interaction (being in a room compared to being in an open park) [9].

Sendor et al. [12] extended the Benford model of interaction during the years. Uses nimbus, focus and awareness ideas on semantic networks objects and their relations. In this method structure of the deleted or updated objects history and relations are built. As this model maintain the history of objects which is very difficult task in CVEs and create an extra overhead.

Greenhalgh et al. [13] used the method of third-party objects integration. The "third-party

objects" provide provision for awareness calculation by using the appropriate factors, which increase scalability. Third party objects may represent features of interaction context, such as crowds, common objects, rooms/ buildings or more abstract factors such as control of the chair or membership of a group. These objects are defined in terms of their activation and effects. It means that what they do and when they do it. There are two classes of effects used in "third-party objects". The first one is the adaptation, which is used to modify existing awareness relationships i.e. suppression or amplification. In second one "the secondary sourcing" concepts of new indirectly forms of awareness are used. The combine effects of adaptation and secondary sourcing is mainly useful to realize the group effects. The group effects include abstraction and aggregation of the whole group [9, 13]. In "third-party objects" among the communicating bodies, simultaneous interactions are required, which create extra overhead. Also in this approach the interaction will change dynamically.

Rodden in 1996 proposed a model of presence for cooperative and/or collaborative applications [14]. This model basically describe the shared nature of the pool of different objects. In this mechanism the objects which are shared and relationship between them form a common space. The users of the virtual environment project their action onto this common space and their action is available publically to all objects which form the common space. Basically the presence model allow a shared workspace of collaborative and/or cooperative applications which based on presence and awareness notions.

The model of dynamic management of interests [15] deals with the problem of presence management in collaborative virtual environments between different users. This model mainly defines user's behaviors and actions taken based on their common of interest. Changes occurs in their center of interest over the passage of time. Main problem in this approach is that when all users of the environment take a common interest i.e. all users interested in a single object, then no interaction will occurs to the remaining objects of the environment. Due to this problem the task will not be completed. Another major problem in this approach is that when the user change their common of interest then the user's performance will be affected.

Bharadwaj et al. [16] proposed a model based on Benford spatial model of interaction that ensure awareness in heterogeneous environments. The model allows the easy choice of sources to users to make interaction with objects in CVEs. For sources provision access rules are used.

A model for three dimension interactions in CVEs was proposed by Otmane et al. [17]. This model gives information to user's assessment to make interaction in CVEs and gives knowledge to users about the system state.

To make help the users to interact in CVEs, workflow based model is used. This model basically provide assistance to users of the environment to improve performance of the users in a single-user interaction (to navigate and select) as well as in multiuser setup (in the case of more users manipulate the same object). This model consists of motor and shared component. The shared component is presented as the shared data space that symbolizes the behavior of users and sources in the CVE. The motor component is presented as a set of assistance functions that deals with data processing from the shared space and provides tools to assist the users during the 3D interaction process. It uses the shared data and applies them via assistance functions (navigation, selection and manipulation functions) on particular sources (focus, aura, nimbus, assistant and avatar) in the CVE [18]. Similarly, Ullah et al. [19] proposed a model for cooperative and/or collaborative tasks in CVEs which is based on the Benford spatial model of interaction [11]. According to this model two users succeed for interaction if their auras collide with same object. In this concept the user awareness is increased and eventually rises the user's performance in CVEs.

3. PROPOSED TASK DISTRIBUTION MODEL

CVE is a computer generated world where two or more user can simultaneously interact with synthetic objects to perform a task. This can be represented in the following way:

$CVE = \{T, O, U\}$
$T = \{T_1, T_2, T_3....T_i\}$ Equation. (1)
$O = \{O_1, O_2, O_3....O_J\}$ Equation. (2)
$U = \{U_1, U_2, U_3....U_m\}$ Equation. (3)

Where T, U and O represent the set of Tasks, Objects and Users as shown in equation 1, 2 and 3.respectively. In order to explain the concept of task distribution model, we consider the scenario of a CVE where the assembly of multiple constituent parts of a product (a complex machine for example) is carried out in the first phase and then they are integrated (assembled) to get the final product in the second phase. This task can be realized in the following two ways.

1. A single group of users performs the assembly of constituent parts sequentially i.e. task T is completed by completing subtasks $T_1, T_2....T_i$ one after another.
2. There are multiple groups of users and each one is assigned a specific task (T_i). In both cases the first step is to select a particular task as shown in Fig. 1. The next step is to determine that how the group members will realize the task? The model proposes two ways in this context.

1. Static task distribution
2. Dynamic task distribution

3.1. Static Task Distribution

In static task distribution, when a task is selected by a group of users then each user in the group will know in advance that which subtask he/she is going to carry out. It means that the user will know about the object he/she will manipulate. For example if the task set T consist of subtasks $T_1, T_2, T_3....T_i$ and the users set U consists of $U_1, U_2, U_3....U_m$, then according to static distribution, T_1 is assigned to U_1 and T_2 is assigned to U_2 of the same group and so on. The respective users will execute their subtasks. Communication and awareness among users in a group during task execution depends on task/subtasks dependency. If the tasks are loosely coupled having less dependency then low awareness will be required and less communication. Similarly if they are tightly coupled with more dependency then high level awareness will be required for which more and frequent communication is needed.

3.2. Dynamic Task Distribution

In dynamic task distribution, no division is carried out in advanced i.e. at start level. Here all users will be actively involved to first complete subtask T_1 then subtask T_2 and so on up-to T_i. In dynamic task distribution starting subtask T_{i+1} all users must be aware that T_i is completed and subtask T_{i+1} is going to start, these information must be communicated to all users of the environments in real fashion The same dynamic task distribution mechanism in CVEs will be followed for subtasks if they consist of sub-subtasks For dynamic task distribution high communication and strong awareness are required during task execution. For dynamic task distribution in CVEs the users as described by equation 3 are divided into Free Users (*UF)* and Busy Users (UB*)* sets as given in the following:

$U = \{UF + UB\}$
$UF = \{UF_1, UF_2, UF_3....UF_k\}$
$UB = \{UB_1, UB_2, UB_3....UB_l\}$

Objects will be selected from objects set as described by equation 2. If object O_j is selected by a user then he/she is included in the busy user set (*UB*). The rest of free (*UF*) users will be candidates for the selection of remaining objects $O_j - 1$. Similarly if a busy user releases the object or completes his task then he/she is included back in the free user set. This process is depicted in Fig. 2.

The dynamic task distribution is explained with the help of following procedure.

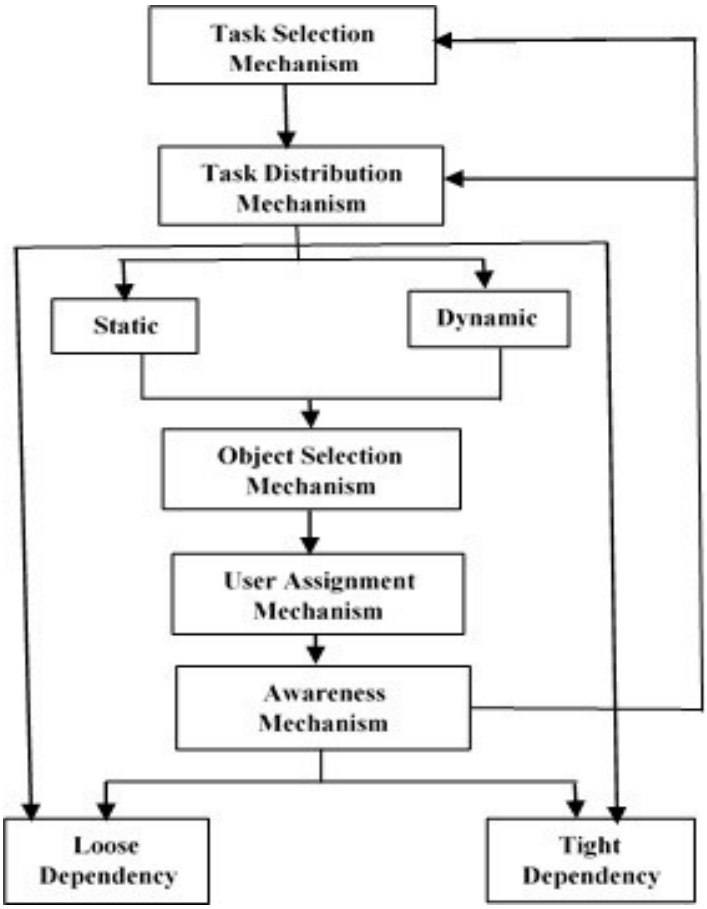

Fig. 1. Task distribution model.

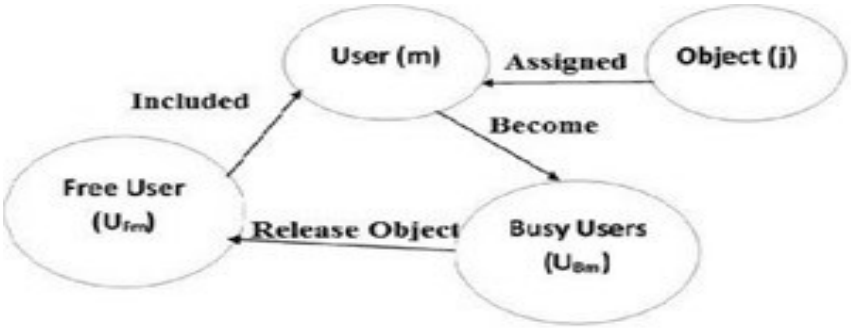

Fig. 2. Objects assignment.

DY NAMIC TASK (*T, O, U*)

[1] For each Task i
[2] Repeat step 3 to 9 for (j=1; $j \leq i$; j++)
[3] Assign O[j] to one of free user from free user set (*UF*)
[4] *UF* become *UB*
[5] Inform user via user awareness modalities i.e. audio, textual
[6] $UF - 1 \leftarrow O_{i-j}$
[7] If O[j] released by *UB* then
[8] $UF + 1 \leftarrow O_{i-j}$
[End of if structure]
[9] Continue

[End of inner Loop]
[10] Task Completed
[End of outer Loop]
[11] Return

3.3. Awareness

It is the knowledge of a user about the presence of other users in the CVEs It deals with the degree, nature or quality of interaction between two objects or users [9]. Communication is required among the users of the CVEs to provide awareness. Various communication modalities are used for awareness like audio, visual and haptic.

3.3.1 Audio Modality

To accomplish a collaborative task in VEs in more realistic manner and to achieve high performance and increase co-presence of users, oral/audio communication is used. It allows users to negotiate and exchange information on various tasks, such as selection/manipulation of objects etc.

3.3.2 Textual/Visual Modality

Various visual modalities like shadow, change of colors, arrows and lightning are used in CVEs to increases user awareness [20]. Textual communication allows users to exchange information on various tasks (releasing and picking of objects), which increases performance and co-presence of collaborative users in CVEs. Targeted and global awareness are the two main types of awareness used in CVEs.

3.3.3 Targeted Awareness

Whenever the selective users inform each other about theirs activities in CVEs, this type of awareness is called targeted awareness. For example if there are more than two groups of users involved in collaborative work. Suppose group 1 is responsible for task T_1 and group 2 for T_2, where the latter is dependent on the former. In this case if group 1 completes its task, then there should be a mechanism to inform group 2 only, so this kind of awareness is called targeted awareness.

3.3. 4 Global Awareness

In global awareness process the users of the CVEs are aware of each other individual activities. When all groups are executing their assigned task then they should be aware of each other activities whenever they want from any location. This kind of awareness mechanism is called global awareness [21].

3.4. Task Dependency

Coupling refers to the degree to which task in CVEs are dependent upon each other. In this regard we defined three type of tasks. (1) tightly-coupled task (2) loosely coupled tasks (3) decoupled tasks. In tightly coupled tasks there exist a strong relationship between two or more tasks/subtasks and hence the dependency will increase due to which high awareness is required during the accomplishment of such tasks/subtasks. In a loosely coupled task/subtasks there exist weak relationship between two or more tasks/subtasks having low dependency. Loosely coupled task/subtasks require low degree of awareness and hence less communication is used. In a decoupled tasks/subtasks, operations on the objects can be performed separately and independently. In static distribution there exist loose dependency and required less communication during task realization whilst in dynamic distribution users are more dependent on each other and thus require more communication.

4. EXPERIMENTATION AND EVALUATION

4.1. Environment

In order to investigate the effect of static and dynamic task distribution. We developed a CVE as shown in Fig. 3. The environment consists of multiple rooms. Each room contains a 3D (cube) object on which a character is displayed as shown in Fig. 3. Users are represented by virtual hands. There is a central room which is different in color from other rooms. The user will search the objects

Fig. 3. Virtual reality scenario.

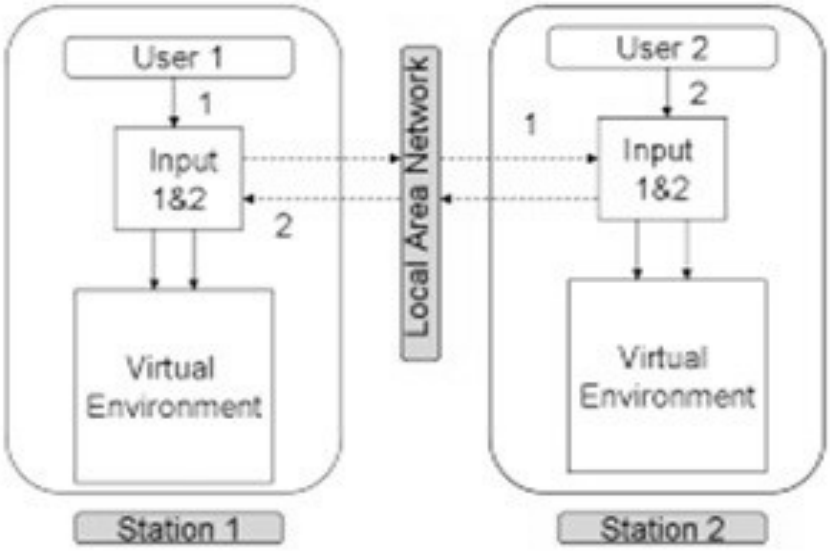

Fig. 4. Experimental setup.

in both static and dynamic task distribution and will bring it to the central room for placement in order to get a meaningful word from the characters displayed on the objects.

4.2. Experimental Setup

Two core i3 laptops having 2GB RAM and NVIDIA graphic cards were used for experimentation. The client server replicated environment is used as shown in Fig. 4. Transmission control protocol (TCP) is are used data transmission between the stations. Server is running on one station and on the other end the client is installed. The stations are connected via LAN using Un-shielded twisted pair cables. The user uses WIIMOTE for interaction with objects. In both VR stations there is a mechanism for getting input from the local as well as remote user. It means that a single user concurrently controls the movement of two pointers (in our case a hand) in the replicated environment connected stations. So if a pointer triggers any event at one station, it

is also simultaneously applied at other station. The objects and user position are changed which is exchanged in real time between two stations. The whole CVE is developed in C++ and OpenGL Library.

4.2.1 Procedure

In order to examine the effect of static and dynamic task distribution on user performance, we carried out the experimentation on different students. Twenty four (24) groups of students voluntarily participated. Most of them were PhD and master having ages from 23 to 34. Each group consists of two students. Before starting the experiment a short briefing and pre-trial about the environment and experiment was given to student in order to make them familiar with the scenario, objects and awareness modalities. All the twenty four groups performed the experiment in five trials each for static and dynamic task distribution. The experiment was carried out under the following four awareness modalities condition.

C1= Dynamic via audio

C2= Static via audio

C3= Dynamic via textual

C4= Static via textual

We recorded the task completion time for each experiment. The time counter started for static and dynamic task when the scenario was loaded to perform the task in CVE and ended when the task was completed. After task completion we gave each user a questionnaire in order to have the subjective feedback.

4.2.2 Task

The users will search the cuboid objects which are placed randomly in CVE and bring the objects to the central room for making the word "UNIVERSITY" under the given conditions C1, C2, C3 and C4 collaboratively as depicted in Fig. 3. In dynamic task distribution the objects' names are communicated to the users via audio/textual modalities in each conditions i.e. C1, C2, C3 and C4. When the object 'U' is picked up by any user then his/her collaborator should be informed to search the next object 'N' and so on, till the task is completed. This type of task distribution is dynamic task distribution. While in static task distribution five objects i.e. 'U', 'N', 'I', 'V' and 'E' are assigned to user1 and the remaining 'R', 'S', 'I', 'T' and 'Y' to user2. Here the task is divided in a way that there exist loose coupling and no dependency during task execution. Each user can independently complete his/her assigned task. Therefore, there will be less communication during task realization.

In the subsections given below the results of task completion time and errors made by the students are analyzed during the accomplishment of the task. Similarly the feedback collected from students through questionnaire are also thoroughly examined and discussed.

4.3. Analysis/ Results

4.3.1 Task Completion Time

For task completion time the ANOVA (F (3, 23) = 4.06, $p < 0.05$) is significant. Comparing the task completion time of conditions C1, C2, C3 and C4, we have 185.7 sec mean (standard deviation 40.24), 156.76 sec (with 39.41 standard deviation), 192.45 sec (with 40.75 standard deviation) and 166.23 with (41.03 standard deviation) respectively.

The results show that C2 (Static via Audio) and C4 (static via textual) have an effect and increase users performance in CVE. Finally it can be concluded that static task distribution have an influence and increase user's performance in CVE as shown in Fig.5.

4.3.2 Errors in Task Completion Time

Selection of a wrong object or its wrong placement (releasing in a room other than the central room) is considered is an errors. The number of errors made during task accomplishment under each conditions were recorded, analysis of which is presented in Fig. 6. The results show that C2

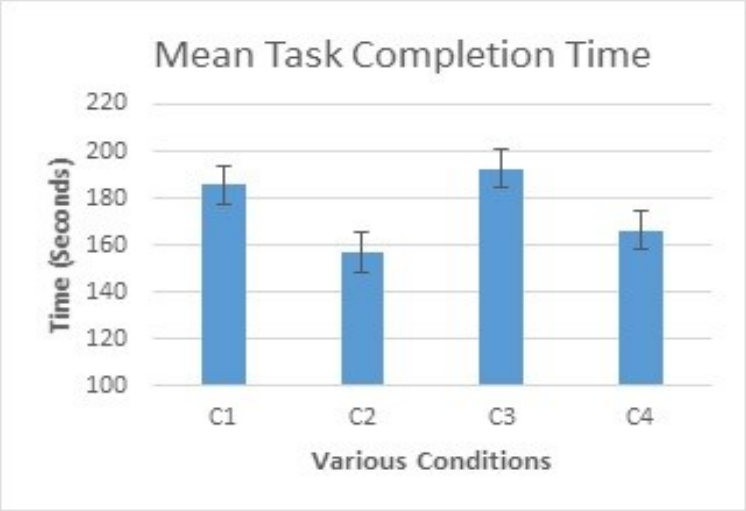

Fig. 5. Mean task completion time.

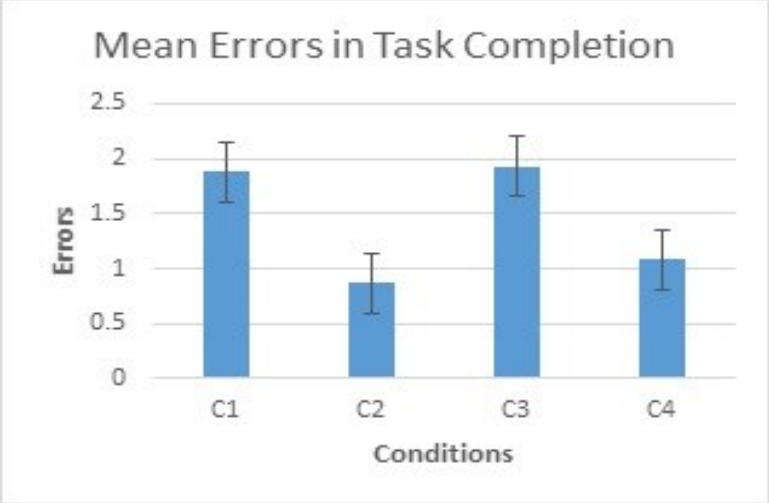

Fig. 6. Mean errors.

(static via audio) and C4 (static via textual) have significantly low errors as compared to C1 (dynamic via audio) and C3 (dynamic via textual) respectively.

4.3.3 Subjective Evolution

In subjective evaluation section the responses collected through questionnaire are analyzed. The questionnaire has five questions, each question contains three to four options for response. The user/subjects select an option for each question.

Question 1: Which task distribution do you prefer?

(a) Static (b) Dynamic

For this question 70% students preferred static while 20% opted for dynamic.

Question 2: Which feedback is the most relevant that you find?

(a) Audio (b) Textual

To this question, conditions audio, textual obtained the preference of 70%, 30% respectively.

Question 3: Task completion is the most difficult under which condition?

(a) C1 b) C2 c) C3 d) C4

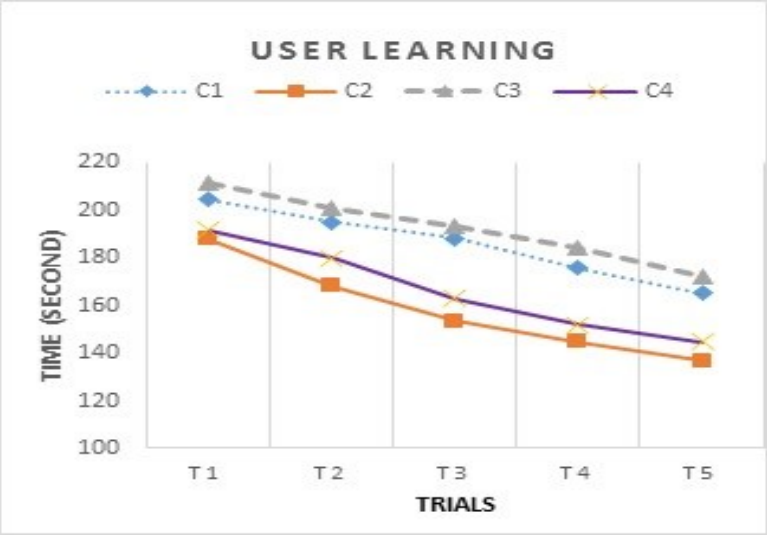

Fig. 7. User learning.

For question no.3, 65% of the students choose condition C3.

Question 4: In which condition do you feel more the presence of your collaborator?

(a) C1 b) C2 c) C3 d) C4

Here 50% of the students opted for C1 while the view of remaining 50% was distributed equally for condition C2, C3 and C4.

Question 5: Which feedback is more helpful in dynamic task distribution accomplishment?

(a) Audio b) Textual

The response of 90% students was in favor of audio feedback and 10% selected textual feedback.

According to the students feedback collected through questionnaire and remarks we observed that static task distribution significantly enhanced user's performance.

4.3.4 User/Subject Learning

Learning is the improvement of group performance during task repetitions. In our experimental setup and execution of the experiment we asked each student of the group to repeat 5 times the previously defined task under each condition. The results show better performance of user in next trial because of the user learning from the environment.

This results of performance improvement is 19%, 24%, 18% and 24% for conditions C1, C2, C3 and C4 (from trials t_1 to $t_{5)}$ respectively as shown in Fig. 7 which means that task learning was more under static distribution.

5. CONCLUSIONS

In this paper, a new model for task distribution was proposed, in which task distribution strategy among multiple users in CVEs was defined. The model assigns the task to collaborating users in CVEs either on static or dynamic basis. In static distribution there exists loose dependency and requires less communication during task realization whereas in dynamic distribution users are more dependent on each other and thus require more communication. In order to study the effect of static and dynamic task distribution strategies on user's performance in CVEs, a collaborative virtual environment was developed where twenty four (24) teams (each consists of two users) performed a task in collaboration under both strategies (static and dynamic). Results revealed that static distribution was more effective and increases users' performance in CVEs. The

outcome of this work will help the development of effective CVEs in the field of virtual assembly, repair, education and entertainment. In future the effect of task distribution model on learning virtual environments and network latency will be investigated.

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Research Article

Daily Life Activities on Smartphones and Their Effect on Battery Life for Better Personal Information Management

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Abstract: The ubiquity of smartphones is evident from the fact that it is present in the pocket of almost every individual. Because of the increasing computing power and the integration of other abundant resources like storage and sensors, smartphones are proving as the most common Personal Information Management (PIM) platform. Smartphones can capture a broad range of users' experiences as compared to a traditional desktop computer which is evident from the numerous smartphone apps available in app markets for the purpose. These applications capture context of a user by utilizing full resources of the smartphone, especially the sensors. However, limited battery power of smartphones has proven to be the most significant bottleneck. Currently, app-based power consumption is estimated which provide only an indication of per app power usage and is of no use to researchers. This research identifies users' common daily life activities on smartphones and critically analyses their effects on battery power. Our approach looks into the problem through the eyes of researchers working in the domain of intelligent and context-aware systems. An Android-based application called Smartphone Task-based Energy Monitoring System (STEMS) is developed for estimating power consumption rates of different daily life activities. The system collects activities and the power consumption data from the participants' smartphones operating on cellular network with GSM/GPRS and Wi-Fi capabilities. It was found that activities requiring internet connectivity are more energy hungry than others. The results so obtained may prove useful to the stakeholders, like app designers and developers, PIM managers, and the end users.

Keywords: Smartphones, power consumption, daily life activities, life logging, battery lifetime

1. INTRODUCTION

Acquiring and keeping of valuable information is a fundamental property of human behavior. However, users' physical and virtual information spaces get overloaded with information accumulated from unfolding their lives. The tremendous increase in information volume generates information overload problem which makes storage, organization, and retrieval of information increasingly difficult. Personal Information Management (PIM) systems are computer-based applications developed to help users in managing their Personal Information (PI) spaces for facilitating their daily tasks and fulfilling their leisure needs [1]. The modern era of PIM started at the end of World War II (1945) when Vannevar Bush proposed an imaginary mechanical device called "Memex" to record an individual's lifetime data (i.e., books, records, and communications etc.) and retrieve them with exceeding speed and flexibility [2]. He assumed

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that extending technology into Memex will not only augment human memory for helping knowledge workers in easing the difficulties of information management but will also facilitate information exchange[3]. Researchers' growing interest in the PIM can be attributed to the advancements in computer technologies. The storage capacity of hard drives is increased significantly and terabytes hard drives are now very common and inexpensive. In addition to storing conventional information, digital storage can store pictures, music, full-motion videos, and photographs, etc. [4]. However, defining meaningful relationships between the information items and ensuring retrieval of right information at the right time is as hard as finding a needle in a haystack. Semantic Desktop approach solves the problem by providing a semantic middleware for integrating desktop applications and data using Semantic Web technologies [5].

Smart phones are modern high-end mobile phones combining the features of pocket sized communication devices with personal computers (PCs) like capabilities [6]. Smartphones have been proven as the highly ubiquitous computing devices with millions of smartphones are in use around the globe. Modern technological advancements (i.e., processor, memory, and operating systems etc.) have enabled smartphone as an ideal tool for future computing. Smartphone provides the same users' experiences as desktop computers with certain additions and improvements. Strong support from the application developers' community has enabled smartphones users to create information in a fashion similar to desktop computers. The available smartphones' applications typically defines users' daily life activities such as audio/video calling, SMS/MMS messaging, web browsing, music listening, videos watching, TV viewing, social networking, e-shopping, gaming, locations visiting, and many more. Smartphones offers numerous characteristics which instigates the need of developing sophisticated PIM systems because sooner or later they will suffer with the same information overload problem. The availability of applications enables users to create thousands of files (i.e., documents, emails, pictures, videos, and audios etc.) signifying the realities and importance of different aspects of their lives. Similarly, smartphone capabilities and features have turned it into ideal lifelogging tool which could use its sensory capabilities to capture contextual cues to annotate users' daily life activities to augment their episodic memories. However, the increasing capabilities of smartphone can be hindered by a number of limitations, importantly power issue which could not be met by the limited power sources. In smartphone, battery size and capacity is severely restricted due to the device size and weight constraints [6]. Smartphone uses rechargeable electrochemical batteries as its power source which is expensive to manufacturer and can run out of charge within a few hours. A modern smartphone featuring with conventional hardware components and applications demands for greater power sources because each one is taking toll on the battery resource [7].

Researchers have investigated energy consumption optimization at different levels (e.g., hardware and software etc.) for extending the battery life. However, smartphone's limited battery power can foster big hurdles and restrictions for using different types of applications. Applications are characterizing users' daily life activities and users have to use a number of applications to execute their daily life activities. Activities via applications creates heavy workloads and requires intensive usage of resources (i.e., processor, network interfaces, sensors, display etc.), that could result into significant energy consumption and could severely affect the capabilities and significances of smartphone such as missing of important mementos etc. Therefore, ranking an individual application for its energy consumption would be an infeasible and dreadful solution. Instead of focusing on accumulation and classification of applications into activities and finding energy consumption rates at activities levels can be of significant importance. This

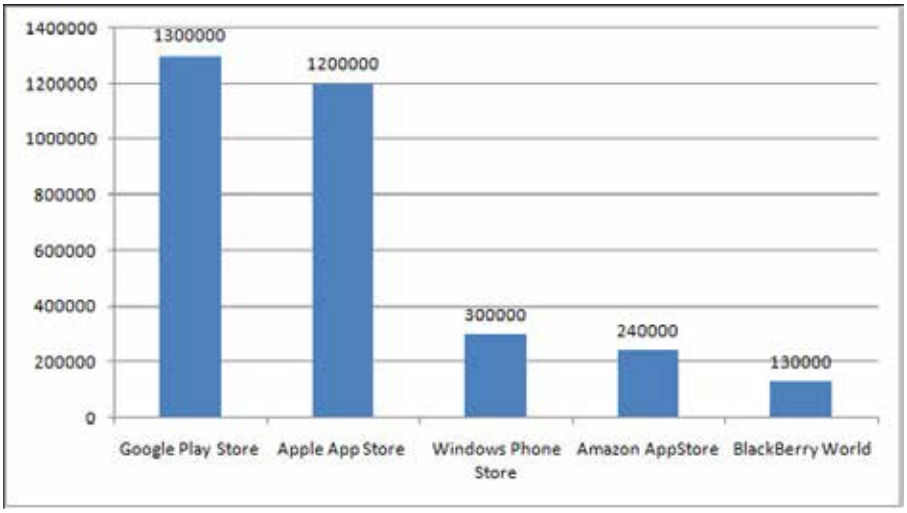

Fig. 1. Number of applications available on different app stores.

investigation will help PIM managers to identify common users' smartphones daily life activities, their power consumption shares, and customize their activity tracking patterns. It will also instigate application developers for developing novel daily life activities energy optimization methods by diagnosing and debugging the highly energy hungry applications used by users' in their daily life activities.

The work reported in this paper is done in the context of our larger project which aims to make a smartphone the most effective Semantic Desktop platform. In this paper, we have presented an approach for analyzing the energy consumption rates of users' smartphones daily life activities. To validate our approach, an Android based application namely Smartphone Task-based Energy Monitoring System (STEMS) is developed which can effectively monitor, record, and analyze the energy consumption rates of the various users' smartphones daily life activities. For representing users' daily life activities, we have divided the available smartphone applications into a number of broad categories such as accessing emails, text messaging, initiating and receiving calls, social networking, watching videos, listening audios, and playing games etc. An exhaustive set of tests have been carried to determine energy consumption rate of each activity explicitly and in conjunction with other activities. Results obtained have been tested, verified, analyzed, and found of significant importance for all of the stack holders: researchers, PIM managers, applications developers, and users.

2. COMMONDAILY LIFE ACTIVITIES ON SMARTPHONE

Smartphone applications shortened "apps" are application software designed to run on smartphones. Initially, apps were aimed for general productivity and information retrieval such as email,calendar, contacts, and stock market and weather information. However, rapid public demands, identification of new application areas, and the availability of sophisticated development tools drove rapid expansion into other categories such asgames,location-based services,e-commerce and e-banking, entertainment, transportation, healthcare and fitness etc. According to statistica[1] that by July 2014 the number of apps available in leading app stores has reached into million as depicted in Fig. 1. In June 2014, Apple had reported of 75 billion apps downloads from its App Store and in July 2013, Google had reported of over 50 billion apps downloads from its app store.

[1] http://www.statista.com/statistics/276623/number-of-apps-available-in-leading-app-stores/

Smartphone has transformed methods of engagements in our everyday lives. The growing penetration of smartphone in our everyday lives has resulted into increased screen time by engaging in numerous activities such as entertainment and social media etc. Now, the time spent using smartphone exceeds the time spent for web usage on computers. Nielson data has shown that today's smartphones users of age 18 and above spend 65% more time each month using apps than they did just two years ago [8]. Similarly, an average smartphone user checks his phone 150 times a day for different tasks and if each interaction lasts for an average of one minute it would mean a user would be using smartphone for more than two hours up to whopping 3.3 hours per day [9, 10]. In a survey, 85% of respondents have concluded smartphones as the central part of their everyday lives and marked them as the major source to remain up to date with loved ones and social events [11].

Over the past few years, the proliferation of smartphones has transformed us into an app-driven society, presenting marketers with new opportunities to connect with consumers by creating more interesting and sophisticated apps to command their attention. However, the number of apps usage varies according to demographics such as in USA the smartphones owners ages 25-44 are found using greatest number of apps with an average of 29 apps per month [8], and South Korea is the top chart country where average smartphones users downloads 40 apps per month [12]. Apps enable users to do more with their smartphones rather than just making phone calls. Thus, makes smartphone as a portal of an ever-growing list of activities. Exact Target survey has indicated that top smartphones users' daily life activities are accessing email (91%), text messaging (90%), getting news alert (62%), watching videos (30%), and getting directions (24%) [10]. Pew Research Center's Internet & American Life Project survey has indicated that most popular smartphones users' activities are taking pictures (82%), test messaging (80%), accessing internet (56%), email (50%), video recording (44%), apps downloading (43%), online health and medical information (31%), and online banking (29%) [11].

Researchers have developed applications to provide reliable data about a user's average smartphone consumption (.i.e. usage time and activities preformed) per day such as Menthal, etc. [13]. To explicitly identify the main users activities on smartphones for this study, an Android based application called Activity Logger is developed. Activity Logger was installed on smartphones of the 50 panelist (i.e., students of the

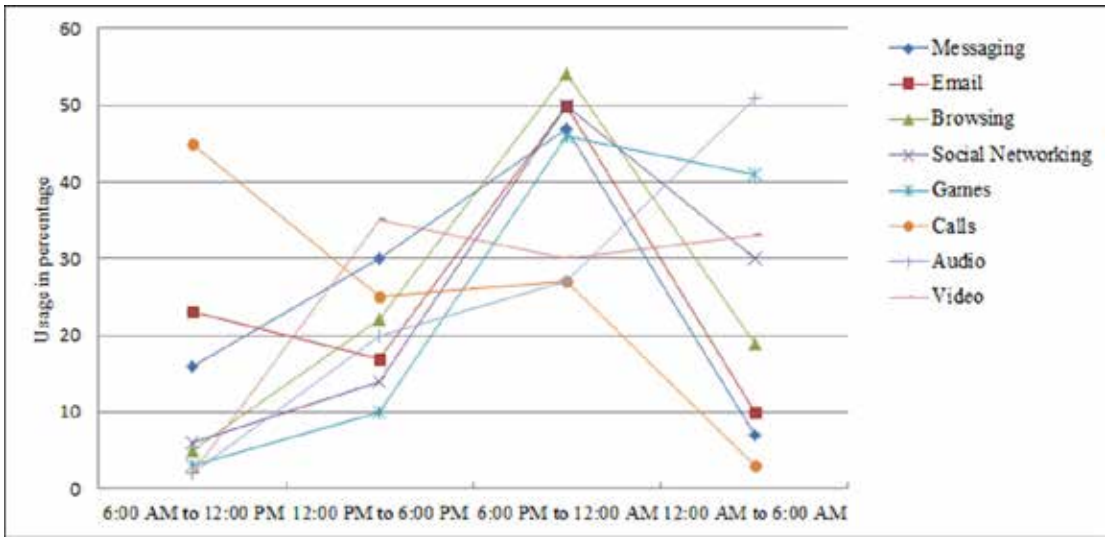

Fig. 2. Users' common daily life activities on smartphone.

University of Peshawar) aging from 18 onward. The sample size is kept fairly small in relation to smartphone owning population due to limitations of time and resources. Activity Logger runs inconspicuously in the background and captures information about applications (i.e., type, name, and usage duration etc.) used by the users while performing different daily life activities in a day. The data is collected on digital tracking of the panelists from March 10, 2014 to March 25, 2014 and stored on the panelists' smartphones. After refining, organizing, and categorizing the collected data, the most common activities performed by the panelists on their smartphones were text messaging, voice calls, entertainment, social networking, web accessing, email accessing, and playing games. The overall results of the survey are shown in the Fig. 2 depicting the most common activities and their execution time in a day.

3. RELATED WORK

A fair amount of research has attempted to investigate that how a smartphone battery power has been consumed. Researchers have concluded the energy consumption as the primary problem and emphasized on smartphone energy management by defining their own ways to save energy. They argued that smartphone energy consumption monitoring is essential and saving energy can increase battery lifetime.

A rich body of research has concluded hardware components as the major source of energy consumption. John et al.[14] have measured and compared the power consumption of several hardware components including CPU, RAM, I/O, memory controller, video, and disk controller under various workloads. CPU and disk controller were found major power consumers. However, under the SPEC CPU suites, RAM can consume more power than CPU due to high memory-bound workloads. Carroll et al.[6]have produced a breakdown power consumption of various hardware components including CPU, RAM, graphics hardware, audio, storage, and various networking interfaces under a number of usage scenarios. They observed non-uniform power consumption by the hardware components in variable scenarios such as GSM in suspended state, and graphics in the idle sate with backlight off etc. Perrucci et al. [15] have compared energy consumption of various components of a smartphone and found that wireless technologies are more energy hungry as compared to others (i.e., display, CPU, and memory etc.). To optimize energy, 2G network is suitable for voice calls and 3G for data connections. Furthermore, Bluetooth has fair applications for small data and Wi-Fi for large data transmission. Abdesslem et al. [16] have described Sense Less which is an automated system for maximizing battery life in mobile sensing applications by leveraging the different energy characteristics of sensors. The system proposed the frequent use of less expensive sensors as compared to energy expensive sensors in location-aware services. Among the sensors, GPS is found more power hungry and accelerometer is less power hungry. Wang et al. [17] have described Energy Efficient Mobile Sensing System (EEMSS) and assumed that continuously capturing contextual information using sensing capabilities of smartphones can consume large amount of battery energy. To significantly improve battery life, they have suggested of empowering only a minimum set of sensors and employing appropriate sensors' duty cycles for recognizing users' daily life activities in real time. Datta et al. [18] have projected that hardware components including sensors and third party applications are the major causes of power consumptions. Display hardware and networking interfaces are found the most energy hungry components. A number of useful tips are suggested for minimizing power consumption by the display hardware, networking interfaces, and CPU etc.

Another group of researchers assumes that smartphones' applications can be the major source of power consumption if not developed with

power consumption management as priority. Liu et al. [19] have augmented that sensors-based applications can be the root cause of energy wastage if they use sensors and their data ineffectively. They have developed a system, called Green Droid, for analyzing sensors-based applications to successfully locate real energy inefficiency problems in them. Oliner et al. [20] have advocated that an application's misbehavior (i.e., known as energy bugs) consumes energy by performing activities which are not intrinsic to the application's functions. They classified applications as energy bugs and hogs where energy hog is an application which drains the battery much faster than an average application and energy bug is an application whose running instance can drain the battery much faster than other instances of the same application. A smartphone application called Carat is developed for collecting data for detecting and diagnosing applications' energy problems by looking for their deviations from typical battery usage. Some of the hogs found in Samsung Galaxy S2 are Facebook, WhatsApp, Andro Sensor, and AVG antivirus. Datta et al. [18] have reported in their study that third party applications displaying advertisements are major causes of power consumption. Ding et al. [21] have described Smart Energy Monitoring System (SEMO) for profiling mobile applications with battery consumption information. File download applications are reported as more energy hungry in the study.

All of these efforts provides enough evidences for calling attention of the researchers for the development of efficient battery energy saving and management methods. However, mostly hardware or applications using hardware components exclusively (i.e., sensing applications etc.) are condemned for excessive battery energy usage. Applications used by users in their daily life activities are of vital importance and can produce significant effects on battery life time. Identifying and estimating activity level energy consumption rates are of importance for a number of reasons such as helping PIM managers to customize their activitiestracking patterns to record more and more daily life activities related data etc. The most relevant work is of SEMO [21], but it has focused onindividual application's level energy consumption monitoring and no detailed statistical analysis, case study, and evaluations has been presented. Furthermore, only few of the applications from the wild have been selected for the study. In this paper, we have presented a method for classifying the available smartphone applications into daily life activities and analyzing energy consumption rates using daily life activities levels. To validate our study, an advanced energy monitoring system called STEMS has been developed for collecting activities'battery usage information from a community of users and ranking activities in power consumption list according to their shares.

4. STEMS METHODOLOGY AND ARCHITECTURE

To calculate and analyze the energy consumption rates of the smartphone applications, we have designed and implemented Smartphone Task-based Energy Monitoring System (STEMS) for Android based smartphones. Since the number of applications on Google Play store has reached into millions, therefore, STEMS first enables users to customize their smartphones by categorizing the installed applications into different categories (i.e., representing activities) which are identified from the survey discussed in section 2 (i.e., text messaging, voice calls, entertainment, and social networking etc.). Second, before collecting data, it checks current status of the battery by determining its temperature level and remaining power etc. Third, the energy consumption data is collected for the active applications during an activity in real time for the duration of the activity. Fourth, it analyzes the applications' energy consumption according to the data collected. The collected data consists of time duration, battery power consumed, and names of the applications used in an activity category. Layered architecture of the STEMS is depicted in Fig. 3.

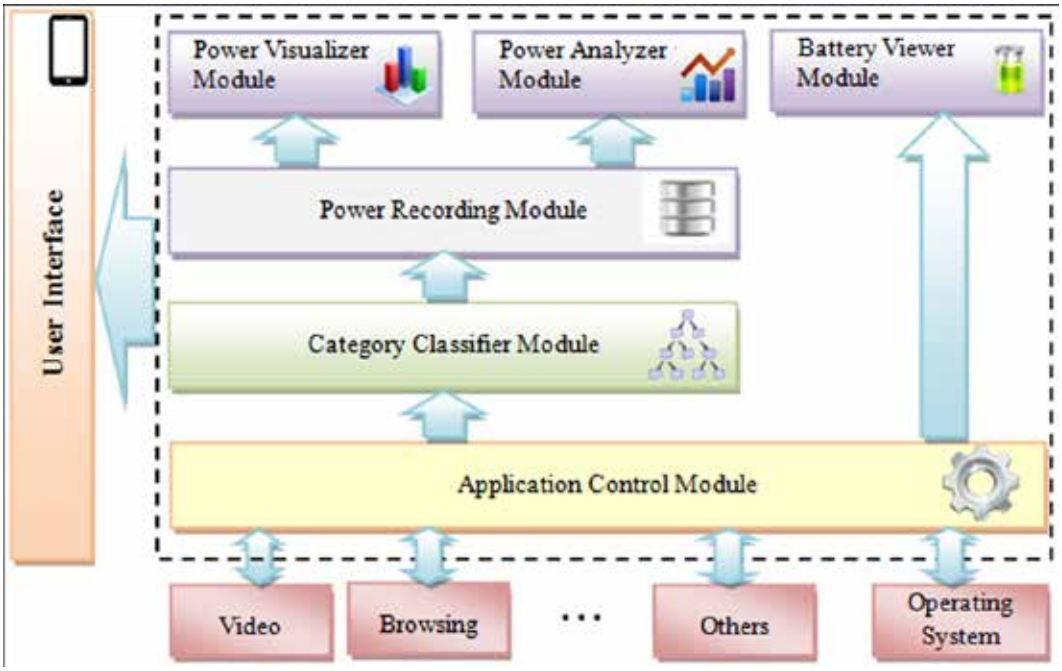

Fig. 3. STEMS architecture showing individual components and their interactions.

Fig. 4. STEMS main user interface.

STEMS is composed of four main components: classifier, investigator, registrar, and decider. Main user interface of the STEMS is shown in Fig. 4. The classifier enrolls the installed applications into different categories. The investigator checks for the information about current state of the battery. The registrar stores numerous information including application name, categories name, time duration, battery information, and battery power consumed in a data store for further processing. The decider analyzes the information stored in data store for determining rates of energy consumption of the activities and ranks the activities according to their consumption rates.

4.1 Classifier

At the present, we have tones of applications developed by the researchers, and professional programmers for answering a number of real world problems. The available applications can be classified into a number of broad categories depending on their functionality. The classifier module checks for the installed applications on a smartphone and enables user to classify them into categories. The overall operation of the module is presented in flowchart in the Fig. 5. Classifier, first, finds the installed applications and retrieves categories information from the database. It enables users to put an application in any existing category or create a new category in real time. It also enables users to switch applications between the categories. Once an application is admitted in a category, it will be treated accordingly.

4.2 Investigator

Investigator is a demon which starts when the application (i.e., STEMS) is started and

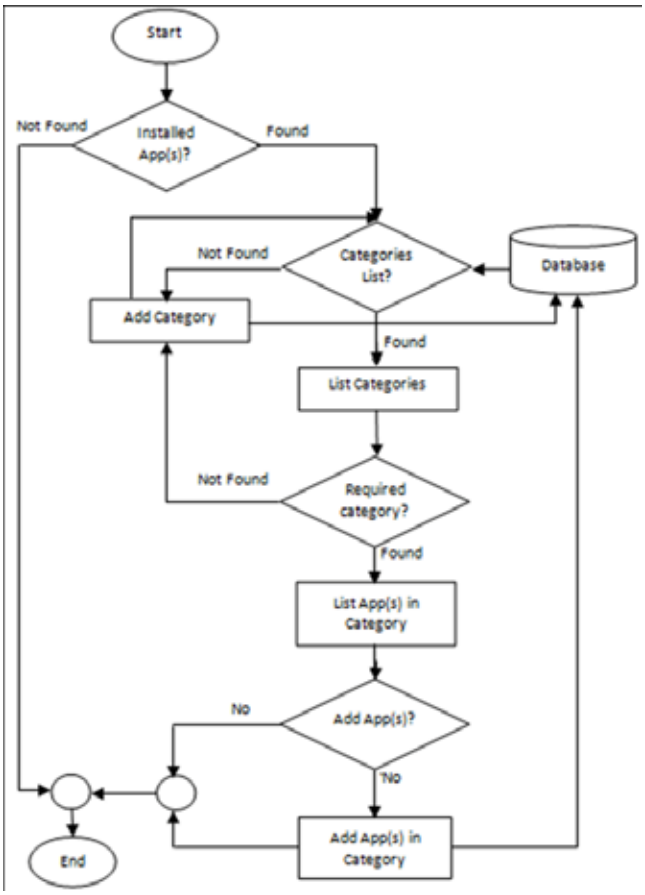

Fig. 5. Flowchart of classifier.

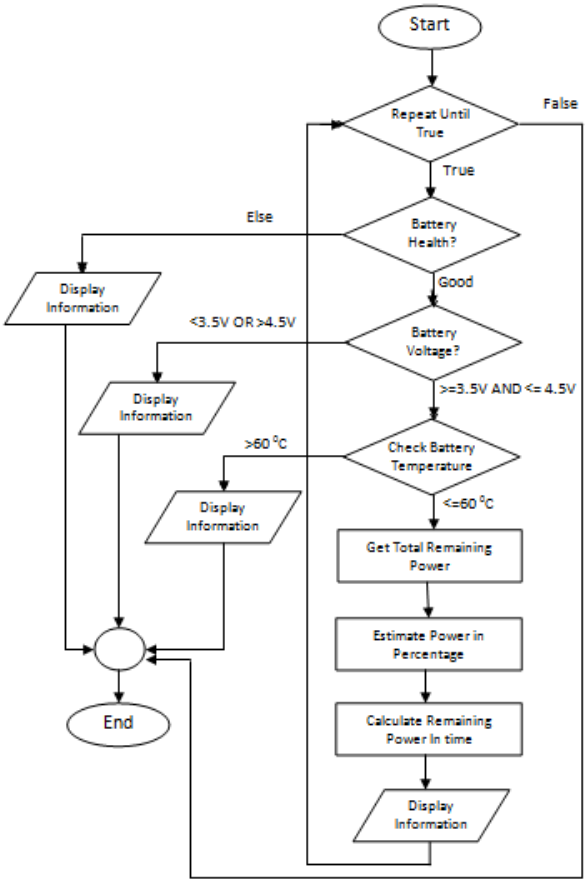

Fig. 6. Flowchart of investigator.

continuously runs in the background inconspicuously for gathering critical information about a smartphone battery. The investigator performs the activities which are essential for any energy monitoring systems and are shown in flowchart in the Fig. 6. First, investigator gets information about vital aspects of a battery including health status, voltage, and temperature. If everything is within the acceptable range, investigator displays information to a user including battery remaining power in percentage, and total remaining power time etc. If any discrepancy is found, investigator will inform user for taking prompt actions. Similarly, investigator remains in the background for continuously monitoring the battery for any critical condition. If any is found, user is informed for taking necessary actions. For example, if battery remaining power is found less than 15%, user will be informed to recharge the battery etc.

4.3 Recorder

Recorder is another important component of STEM which starts with the application and periodically records information about the battery and currently running applications. The overall activities of recorder are shown in Fig. 7. First, recorder store information about applications and their respective categories in the database. Recorder periodically checks for the applications currently running using the information stored in the database. If a new application is found, it will check for its category. If already assigned, recorder will store information related to the applications (.i.e. name and its category etc.), an application startup time, and the battery level at the start time etc. otherwise user will be prompted for assigning application into a category. If a previously active application has been shut down, it will store information related to application end time, the battery level at the end time, the total

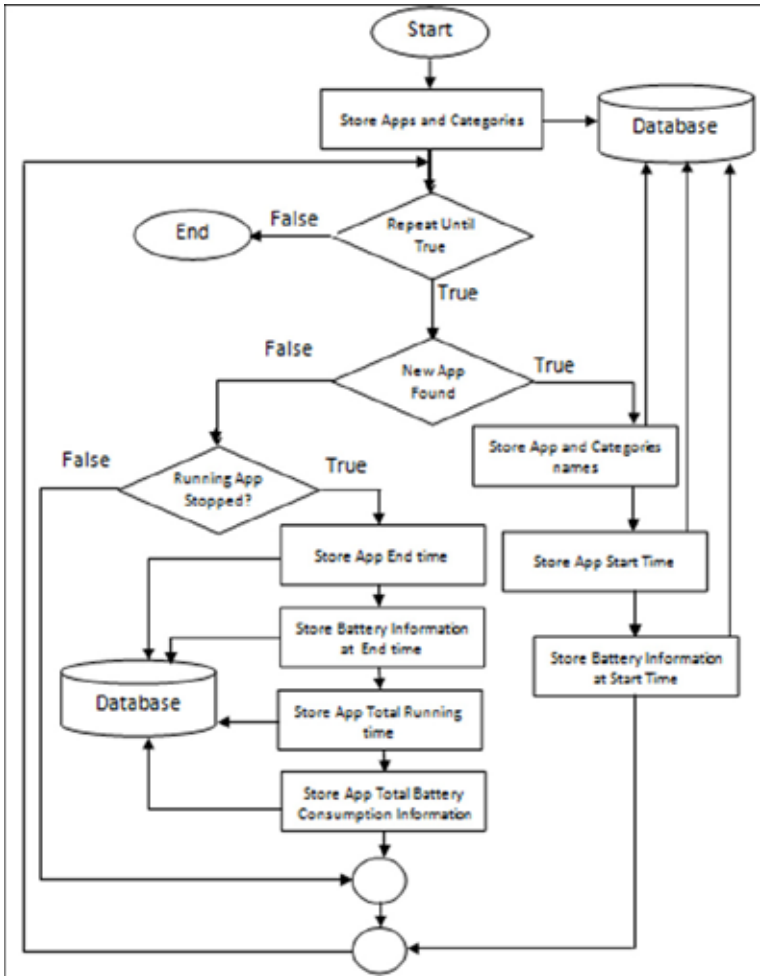

Fig. 7. Flowchart of recorder.

amount of time application has been executed, and the total amount of battery power consumed. This periodic checking can impose excessive burden on a device. Therefore, record interval is defined and set to 2 minutes.

4.4 Analyzer

Analyzer is the decision maker of the STEM which analyzes the information stored by recorder for calculating the energy consumption rates of individual applications in a category, summing them up, and ranking the applications' categories using their energy consumption rates. First, the analyzer retrieves information related to applications, their categories, and their energy consumption from the database. The retrieved information is analyzed and the energy consumption of individual applications in each of the category is estimated. The applications' energy consumption estimations in a category are used for determining the energy consumption rates of the individual categories. The calculated information are used for ranking categories by their energy consumption rates.

5. STEMS IMPLEMENTATION

Using the architecture (i.e., discussed in section 4), STEMS has been developed for the android based smartphones. The system is programmed in Java and developed in Android Studio with Android SDK tools version 5.0 (Lollipop) [2] and others. The popularity of Java programming and the increasing adoptability of Android as operating system by the

[2] https://developer.android.com/sdk/index.html

Fig. 8. Battery information displayed by the investigator.

Fig. 9. Applications classification into activities by the classifier.

smartphone vendors ensure the portability and scalability of the STEMS.

5.1 Battery Information Display

STEMS is composed of several activities where each one is designed for performing a specific function. After installing STEMS on a smartphone, the main interface will appear on the screen at its startup time. The main interface consists of several controls including buttons. The investigator will get started once the "Battery Information" button is clicked on the main interface. The investigator is implemented as a service which will remain in the background inconspicuously monitoring various states and behaviors of the battery. However, it will initiate an activity which will display battery information including type, technology, voltage, remaining time, CPU usage, temperature, and health etc. as shown in Fig. 8. The investigator also monitors battery power during the experiment time and intimates users accordingly.

5.2 Categorizing Applications

Clicking "Categorize" button on the main interface starts classifier. The classifier is implemented as tab activity with categories and applications tabs. The category tab contains some pre-defined categories and enables users to create new categories as well. The applications tab reads and lists applications already installed on a smartphone. With each list entry, a pull down list of already created categories would appear for enabling users to enroll application in a category. Similarly, users can also remove an application from a category, and put it into another category.

5.3 Recording Power Information

Clicking "Record" button on the main interface starts recorder. The recorder is implemented as a service for running in the background inconspicuously and storing power consumption information of the applications' category wise in SQLITE database during the experiment time. The stored information includes application id, category id, start time, end time, start time battery power, end time battery power, and total power consumed etc. The database is created in Android's native SQLITE which can be exported to computer for performing advanced analysis using Excel, Navicate Lite, and Origin applications.

5.4 Analysis and Results

Once the data has been collected and recorded by the recorder from the experiments, analyzer can be started by clicking the Analyzer button from the

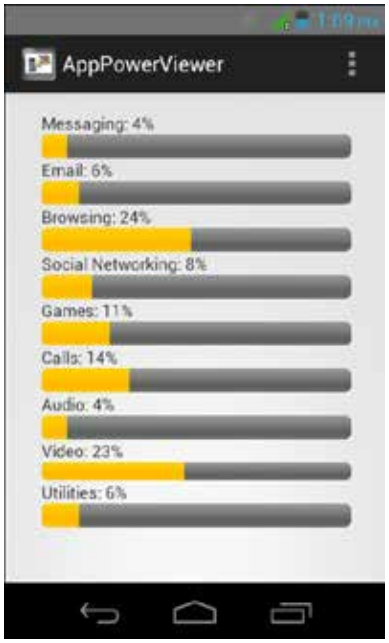

Fig. 10. Activities power consumption results displayed by the analyzer.

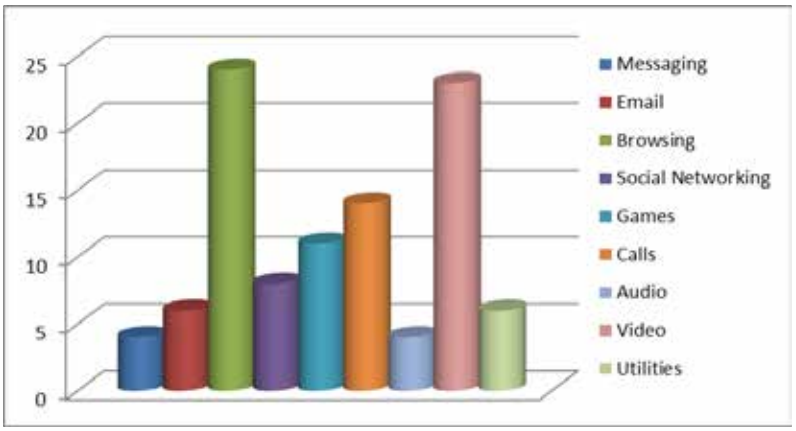

Fig. 11. Analyzer results showing the amount of energy consumed by the activities.

main interface. The analyzer read the data stored in the SQLITE database, compute rate of total power consumption application wise and category wise, and ranks the categories using their energy consumption rates.

6. STEMS TESTING AND EVALUATION

STEMS is tested on QMobile A12 smartphones running on Android Ice Cream Sandwich 4.0.3 and connected to a cellular network with GSM/GPRS capabilities. In order to demonstrate the accuracy of STEMS, the application is tested closely in real world domains. A testing strategy was defined where three participants were given QMobile A12 smartphones installed with STEMS. The participants were instructed to use applications in each of the categories, identified in section 2, for at least 30 minutes each day. Categories were created using the prescribed criteria and applications belonging to the various categories were downloaded and installed from Google's Android Market, the Google Play as shown in Fig. 9. The tests were conducted continuously for a week. The collected data was analyzed, ranked, and displayed by the analyzer as

shown in Fig. 10. Analysis of the data collected from each participant after completion of the tests revealed that from the course of users' activities web browsing and watching videos were the most energy hungry activities and can result in significant battery power loss. However, messaging and audio were found the least energy hungry activities. The results remained the same for each participant for the entire testing period.

To validate and ensure the accuracy of the data collected by the STEMS, data stored in the STEMS's database was imported in to MS-Excel and presented in a bar chart as shown in Fig.11. Results depicted by the bar chart in MS-Excel werefound exactly the same which wereprovided by the analyzer.

7. CONCLUSIONS

PIM systems were needed to solve the information overload problems on personal computers (PCs) by enabling users to store, organize, and retrieve their personal information conveniently. The idea of Semantic Desktop was coined as a solution to the problem by leveraging the Semantic Web ideas and technologies. A Semantic Desktop uses ontologies to develop a mental model for defining meaningful relationship between the information items on a PC. However, the paradigm has been shifted and today's smartphone is proven as sophisticated computing platform having the same communication and technological capabilities as PCs. Over the past few years, the popularity of smartphones has turned us into applications driven society enabling developers to develop applications for almost all walks of life. A vast number of applications are developed for enabling users to execute their routine activities. Furthermore, smartphone capabilities and features has enabled it as de-facto lifelogging device for capturing information related to users' daily life activities and use them for augmenting humans' organic memory. Sooner or later the smartphone will suffer with the same information overload problem because of extensive data created and captured during daily life activities. For developing an effective smartphone PIM system, users' common daily life activities and their effects on battery power are needed to be diagnosed and analyzed. The inefficient execution of activities could result in significant loss of battery power which could severely affect the capabilities and significances of a smartphone such as missing of important mementos.

This research work is a part of our long time efforts to leverage the ideas of Semantic Desktop for solving the PIM problem on smartphones. In this paper, we have presented a profound analysis of the energy bugs introduced by the users while performing their daily life activities on smartphones. We have articulated that how users' smartphones activities can contribute to the overall power consumption and which of them is of the vital nature. First, a survey is conducted for identifying the most common users' smartphones activities in the wild. Second, the design, implementation, and evaluation of testing application called Smartphone Task-based Energy Monitoring System (STEMS) is presented. STEMS is Android based and provide enormous function for monitoring status of the battery, enabling users to classify installed applications into categories for representing users' activities, power consumption data collection during activities, and analyzing data for ranking activities according to their power consumption rates. STEMS is deployed on users' smartphones for power consumption data collection in real world scenarios under a strategy. Results obtained are of significant importance confirming that ineffective use of applications in activities can contribute to greater battery power loss. Results revealed us that web browsing and videos watching are the most energy hungry activities. This investigation will be helpful for all of the stack holders (i.e., researchers, PIM managers, developers, and users etc.) to develop methods for lowering the overall energy consumption rates of the daily life activities for performing more and more activities and capturing enormous amount of data related to them.

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Research Article

Intercultural Challenges in Offshore Software Development Outsourcing Relationship: An Empirical Study

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Abstract: The importance of intercultural challenges is recognized by both the practitioners and researchers in offshore software development outsourcing (OSDO) relationships. These challenges affect almost all the activities involved in offshore software development outsourcing relationships especially communication, mutual understanding, interpretation and decision making processes etc. which in turn leads to project failure. In our previous published study we identified, through systematic literature review (SLR), various intercultural challenges faced by vendors in OSDO relationship. The aim of this study was to validate these findings through industry practitioners and to identify its intensity as well as to identify any other intercultural challenges, faced by vendor organizations in OSDO relationships. We performed questionnaire surveys with 41 experts from different software companies. A seven point likert scale was used to determine the significance of each intercultural challenge. Our findings indicate that all the intercultural challenges are critical for OSDO vendors. We further analyzed these challenges based on different variables, such as company size, company type, expert's job/position etc. We have identified that there is no significant difference in the intercultural challenges based on company type and expert's experience level. We identified that "language and language proficiency" is the most commonly agreed and "difference in social behaviour" is the most commonly disagreed intercultural challenge in the category of both sizes of company. Similarly "language and language proficiency" is the most commonly agreed challenge based on experts job positions.

Keywords: Intercultural challenges, offshore software development outsourcing, vendors, empirical study

1. INTRODUCTION

Offshore software development outsourcing (OSDO) is a software development strategy used by various organizations spread across different temporal, cultural and geographical locations around the world. Information system services are transferred from one country to another in OSDO [1]. Services are provided by remote organizations, called vendors, to the client organizations. Indian vendors stood first in providing high quality software to their clients by using software outsourcing as their business strategy [1, 2]. The benefits this strategy provides to client and vendor organizations increase its use globally.

Factors like low development cost and higher availability of resources [3], high quality of software products [4], round the clock development [5], and access to latest technologies [6] attract companies towards offshore software

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development outsourcing. The primary reason behind the adoption of OSDO is always low development cost however a latest study [7] stated two key causes for the adoption of OSDO: Firstly, enlarged workers requirements due to large number of software projects, secondly high maintenance charges and inadequate experts at onshore locations.

A number of project failures have been reported in offshore software development outsourcing. Client and vendor's organization geographical separation causes difficulties in face to face meetings [8]. Geographical, temporal and cultural distances negatively affect communication and increase coordination overheads [9-11]. Coordination and control problems arises in OSDO during project work division and assignment [12]. Similarly, software components developed by distributed teams cause many technical issues in integration [13].

Besides the aforesaid issues cultural distance is another issue in OSDO relationships [10], [14]. Client and vendor organizations' cultural incompatibilities and poor relationship management caused many projects failure i.e. partial or complete [4]. Cultural factors have a great impact on the communication, perception and the relationships between the clients and vendors [15]. Similarly cultural and language differences among team members reduce corporation and communication which may result in misunderstandings [9]. To realize the advantages of OSDO we need to address these intercultural challenges. However, despite the significance of intercultural challenges in OSDO relationships, little empirical research has been conducted. In our previous work we have identified numerous intercultural challenges confronted by vendors in OSDO relationships through SLR and has been published [16].This study aims to empirically validate, in OSDO industry, the outcomes of the SLR and to identify any new challenge other than the existing ones. To do so, we formulated the following research questions:

RQ1: What are the intercultural challenges, as identified in the real world, faced by vendors in OSDO relationships?

RQ2: Do the identified intercultural challenges vary based on company type?

RQ3: Do the identified intercultural challenges vary based on expert's experience?

RQ4: Do the identified intercultural challenges vary based on company size?

RQ5: Do the identified intercultural challenges vary based on expert's position?

2. BACKGROUND

The significance of cultural understanding and the vital role it plays in the IT field has largely increased over the last twenty years [17]. Cross-cultural inconsistencies and miscommunication hinder the efficiency of software outsourcing [4]. Culture is hard to describe and that is why culture has limited definitions in software outsourcing research field [4]. Culture has been defined in several ways in the literature [18]. A renowned Anthropologist and Sociologist Sir Edward Tylor [19] describes that culture spans knowledge, belief, art, morals, law, customs and any other capabilities and habits acquired by man as a member of society. It is clear from the definition that almost all the activities of life are being influenced by culture. It affects software outsourcing activities i.e. cooperation and coordination, create language barriers and misunderstandings [20]. Vendors must know their client's culture and its effect on software development activities and their relationships [14], [21]. Similarly understanding of both culture and language of the client organization are necessary for the developers [22]. Because language dissimilarities between development teams can result in misunderstanding and information sharing issues [23].

OSDO involves workers from several geographical sites and cultural backgrounds. This rises the need for research on the influence of

cross cultural and national cultural problems [24]. Culture has been identified as a critical factor for vendor organizations in OSDO relationships in our previous research project [14, 25]. Cultural importance cannot be ignored in OSDO relationships, because cultural problems can "make and break an offshore project" [26].

3. RESEARCH METHODOLOGY

3.1. Survey Design

A Survey research method is used to empirically verify and complement the results of our previously conducted SLR [16]. We took guidance from some previously published studies in order to perform our survey [27-29]. The reason to employ survey method is to target wide range of population in a short span of time with a reasonable budget. In this study, online survey is conducted with software engineering practitioners with the help of Google Doc. This method is considered appropriate for collecting self-reported qualitative and quantitative data from a huge number of people [30]. A survey can be a single or a collection of many data collecting methods such as questionnaires, interviews and others [31]. A questionnaire was used for data gathering because of many reasons such as gathering data from a huge span of people and available resources.

We used structured questionnaire for collecting data from the offshore software outsourcing experts. The questionnaire contained intercultural challenges identified through systematic literature reviews. Apart from the closed ended questions, we placed some open ended questions to find any other intercultural challenge. Seven point likert scale was used to describe the significance of the identified intercultural challenges. The respondents were requested to choose one of the seven options, i.e., Strongly Disagree, Moderately Disagree, Slightly Disagree, Not Sure, Slightly Agree, Strongly Agree, Moderately Agree.

A pilot survey was conducted to validate the questionnaire before sending and posting it on the web. Pilot survey helps in checking the practicability of the web-based survey and also to know the problems in answering the questionnaire. After designing the questionnaire, the secondary author performed piloting of the questionnaire by sending to five members of Software Engineering Research Group (SERG) University of Malakand and revised the questionnaire according to their feedbacks.

3.2. Data Sources

The main objective of this survey was to collect data on intercultural challenges faced by vendors in OSDO relationships from software outsourcing experts/practitioners in the industry. We posted a request for participation in our questionnaire survey to different online groups on linkedin as shown in the Table 1. Apart from this we also invited offshore software outsourcing companies and authors of industry papers to take part in the questionnaire survey. The list of the offshore software outsourcing companies is given in Table 2. From this participation a total of 117 participants show their willingness.

3.3. Data Analysis

A total of 44 participants responded to the survey, among them 3 responses were rejected because of our quality criteria. Hence, 41 responses, showing a response rate of 35%, were selected and used for the analysis.

Frequency analysis method was used for the analysis of the collected data, because it is useful for the management of descriptive information. Frequency tables were used to report the percentages and number of occurrences of each data variable. Frequencies can be used for numeric as well as ordinal/nominal data and are helpful for contrasting and comparing across group of variables or within groups of variables. Each intercultural challenge is analyzed by counting its existence in the questionnaires and the articles. The relative significance of each intercultural challenge is identified by comparing the existences

Table 1. Summary of online outsourcing professionals groups.

S/ No	Group's Name	Number of Members (at the request time)	Date request posted
1	Software Development Outsourcing to Pakistan	167	5th January, 2015
2	Global Sourcing	52,669	5th January, 2015
3	Software Outsourcing Services in Europe	1,297	5th January, 2015
4	Outsourcing and Offshoring	29,956	5th January, 2015
5	IT/Software Development Outsourcing & Offshore	19,123	5th January, 2015
6	Outsourcing 2 India	8, 067	6th January, 2015
7	Global sourcing professionals	10,000	6th January, 2015
8	India GIS outsourcing and Offshoring	185	6th January, 2015
9	BP0-Business Process Outsourcing	24, 789	6th January, 2015

Table 2. Summary of Software companies in Pakistan.

S. No.	Software Company Name	Date the request sent
1	Datumsquare IT Service	5th January, 2015
2	Seven Software Develop-ment (Private) Limited	5th January, 2015
3	Developer Desk Technologies	9th January, 2015
4	DiscreteLogix	5th January, 2015
5	Techaccess Private Limited	5th January, 2015
6	StepNex Services (Pvt) ltd	7th January, 2015
7	Trend micro logics	7th January, 2015
8	Grey Beard Solutions	9th January, 2015
9	Vizteck Solutions	5th January, 2015
10	xFlow Research	5th January, 2015

of one intercultural challenge against another intercultural challenge.

4. RESULTS AND ANALYSIS

4.1. Intercultural Challenges Identified via Questionnaire Survey

For RQ1, Table 3 depicts the list of intercultural challenges identified via the questionnaire survey. The outcomes show that more than 65% of the respondents agree that all the intercultural challenges are important. 'Organizational culture' is the intercultural challenge that most of the respondents agreed with i.e. 100%. Therefore, we suggest vendor organizations to emphasis on 'organizational culture' in order to successfully complete OSDO relationship activities.

According to our results "language and language proficiency", "response to time" and "communication style" are the 2nd most agreed, i.e. 95%, intercultural challenges for OSDO vendor organizations. "Communication style" and "language and language proficiency" were also identified as critical intercultural challenges in the SLR results as discussed in section 4.1. Various studies mentioned "language and language proficiency" and "organizational culture" as the significant intercultural challenges for OSDO vendor organizations. Focusing on these two

intercultural challenges will result in efficient communication which is the backbone of any OSDO project.

Third most important intercultural challenge identified through questionnaire survey is the "professional culture" i.e., 92%. Difference in professional culture hinders individual knowledge share ability.

Other important intercultural challenges are: "difference in mutual understanding" – 87%, "different work ethics" – 85%, "attitude towards authority" – 82%, "education system" – 78%, "national culture" – 73%, and "difference in social behaviour" – 68%. These findings validate and complement the findings of the SLR [16]. More than 65% of respondent's willingness shows the importance of these intercultural challenges for OSDO vendor organizations. We suggest OSDO vendors to concentrate on these intercultural challenges in order to establish long lasting relationship with their clients.

Our results show that less than 22% of the respondent disagree that the identified intercultural challenges are not barriers for the OSDO vendors. This low response indicates that the identified intercultural challenges are very important for the vendors and must be handle in order to achieve success in OSDO activities. "Difference in social behaviour" is mentioned as the most unimportant intercultural challenge i.e. 21%. Other most unimportant intercultural challenges include "national culture", "different work ethics" etc. as shown in Table 3.

Table 3 depicts that less than 12% of the respondents are neutral about the identified intercultural challenges. The low percentage of the neutral respondents assures that the identified intercultural challenges are very important for the OSDO vendors and must be addressed properly.

4.1.1. Intercultural Challenges for OSDO Vendors Based on Company Type

We got responses from 41 OSDO experts during our questionnaire survey. These experts are form two types of OSDO vendor organizations i.e. national and multinational. The distribution of intercultural challenges based on company type in given in Table 4. In Table 4, DA=Disagree, A=Agree and NS=Not Sure. We gathered the results of slightly, moderately and extremely agree choices into category A. Similarly results of slightly, moderately and extremely disagree choices were gathered into DA category. Respondents which are neither agree or disagree are placed in NS=Not Sure category.

Our results indicate that experts from both company types are agreed with all the intercultural challenges as shown in Table 4. More than 69% of the experts in national companies and more than 66% of the experts in multinational companies are agree with the importance of the intercultural challenges for OSDO vendors. The percentages of the intercultural challenges across the company types are discussed below:

"Organizational culture", "language and language proficiency", and "communication style" are the most agreed intercultural challenges in national companies, i.e., 96%. Whereas "Response to time" is the most agreed intercultural challenge in multinational companies, i.e., 100%.

"Response to time" – 88% in national companies and "language and language proficiency", "difference in mutual understanding", and "professional culture" in multinational companies are the 2nd most agreed intercultural challenges.

In disagreed list (DA), "difference in social behaviour" – 15% is the most disagreed intercultural challenge in national companies. Similarly "national culture" – 33% and "difference in social behaviour" – 33% are the most disagreed intercultural challenge in multinational companies.

In 'Not Sure' (NS) list, 15% of the respondents in national whereas 13% of the respondents in multinational companies are

Table 3. Summary of intercultural challenges identified through empirical study.

S. No.	Intercultural challenges	Experts Perception (n=41)									
		Positive				Negative				Neutral	
		EA	MA	SA	% of Positive	ED	MD	SD	% of Negative	NS	%
1	Language and language proficiency	27	9	3	95	1	0	0	2	1	2
2	National culture	10	12	8	73	3	2	2	17	3	7
3	Organizational culture	16	18	7	100	0	1	1	4	1	2
4	Professional culture	20	8	10	92	0	0	1	2	4	9
5	Response to time	22	8	9	95	0	0	1	2	2	5
6	Difference in mutual understanding	14	15	7	87	1	0	2	7	2	5
7	Attitude towards authority	11	15	8	82	0	2	2	9	4	9
8	Difference in social behavior	12	9	7	68	2	5	2	21	4	9
9	Different Work ethics	15	12	8	85	0	2	3	12	2	5
10	Education system	14	12	6	78	0	3	1	9	5	11
11	Communication style	23	9	7	95	1	0	1	5	1	2

Table 4. Summary of intercultural challenges based on different Company types.

S. No.	Intercultural challenges	Expert Responses = 41						Chi Square Test (Linear-by-Linear association $\propto$ = 0.05), df=1	
		National (N = 26)			Multinational (N = 15)				
		A	DA	NS	A	DA	NS	X^2	P
1	Language and language proficiency	25	0	1	14	1	0	0.060	0.807
2	National culture	21	2	3	10	5	0	1.495	0.221
3	**Organizational culture**	**25**	**0**	**1**	**13**	**2**	**0**	**4.658**	**0.031**
4	Professional culture	22	0	4	14	1	0	0.144	0.704
5	Response to time	23	1	2	15	0	0	0.567	0.451
6	Difference in mutual understanding	22	2	2	14	1	0	0.591	0.442
7	Attitude towards authority	22	1	3	11	3	1	0.014	0.904
8	Difference in social behavior	18	4	4	10	5	0	1.126	0.289
9	Different Work ethics	22	2	2	12	3	0	0.000	0.988
10	Education system	21	2	3	11	2	2	0.122	0.727
11	**Communication style**	**25**	**1**	**0**	**13**	**1**	**1**	**4.573**	**0.032**

neutral about the identified intercultural challenges.

"Difference in social behaviour" is the most commonly disagreed intercultural challenge in both the companies. The two hypotheses that were observed are given below:

Null hypothesis (H0): There is no significant difference among the intercultural challenges based on company type.

Alternative hypothesis (H1): There is a significant difference among the intercultural challenges based on company type.

It is clearly evident from Table 4 that only two intercultural challenges ("organizational culture" and "communication style") have value of 'p' less than 0.05 therefore we accept the alternative hypothesis (H1) for these two intercultural challenges. The following are the formulated alternative hypotheses for each case: "Organizational culture" and "communication style" is the most agreed intercultural challenge in

national companies. Whereas in multinational companies both of these intercultural challenges are ranked as the 3rd most agreed intercultural challenges.

4.1.2. Intercultural Challenges for OSDO Vendors Based on Expert's Experience

We have divided the total number of respondents into three levels based on their experience. The three levels are junior level experts having experience range of 1-3 years, intermediate level experts having experience range of 4-6 years and senor level experts having more than 6 years of experience in OSDO as shown in Table 5.

From Table 5 it is clear that all the three level of experts are agree with all the intercultural challenges. More than 68% of the junior level experts, more than 69% of the intermediate level experts and 88% of the senior level of experts consider that the identified intercultural challenges are important for OSDO vendors. The percentages of the different intercultural challenges based on the experts level is given below:

In junior level experts list "language and language proficiency", "organizational culture", "response to time", and "communication style" are the most agreed intercultural challenges i.e. 94%. 'Professional culture' – 100% is the most agreed intercultural challenge according to intermediate level of experts. Similarly senior level experts consider "language and language proficiency", "organizational culture", "professional culture", "difference in mutual understanding", "different work ethics" and "communication style" most important intercultural challenges for OSDO vendors i.e. 100%.

"Difference in mutual understanding" – 89% in junior level, "language and language proficiency" – 92% and "response to time" – 92% in intermediate level, and "national culture" – 88%, "response to time" "difference in attitude towards authority" – 88%, "difference in social behaviour" – 88%, and "education system" – 88% in senior level experts list are the 2nd most agreed intercultural challenges.

"Difference in social behaviour" – 31% and "national culture" – 30% are the most disagreed intercultural challenges in junior and

Table 5. Summary of intercultural challenges based on expert's experience level.

S. No.	Intercultural challenges	Expert Responses = 41									Chi Square Test (Linear-by-Linear association ∝ = 0.05), df=1	
		Junior (N = 19)			Intermediate (N = 13)			Senior (N = 9)				
		A	DA	NS	A	DA	NS	A	DA	NS	X^2	P
1	Language and language proficiency	18	0	1	12	1	0	9	0	0	0.010	0.921
2	National culture	14	3	2	9	4	0	8	0	1	1.456	0.228
3	Organizational culture	18	1	0	11	1	1	9	0	0	0.575	0.448
4	Professional culture	14	1	4	13	0	0	9	0	0	0.119	0.73
1	Response to time	18	1	0	12	0	1	8	0	1	1.089	0.297
6	Difference in mutual understanding	17	1	1	10	2	1	9	0	0	0.220	0.639
7	Attitude towards authority	16	1	2	9	3	1	8	0	1	0.296	0.587
8	Difference in social behavior	10	6	3	10	3	0	8	0	1	0.260	0.610
9	Different Work ethics	16	2	1	9	3	1	9	0	0	0.063	0.802
10	Education system	13	2	4	11	2	0	8	0	1	0.018	0.893
11	Communication style	18	0	1	11	2	0	9	0	0	0.400	0.527

intermediate level experts lists respectively. Whereas none of the senior level experts disagree with any of the intercultural challenges as shown in Table 5.

21% of the junior experts, 7% of the intermediate experts, and 11% of the senior experts were not sure about the intercultural challenges.

The results show more similarities than differences among the intercultural challenges across different expert's level. "Language and language proficiency" and "organizational culture" are the most commonly agreed intercultural challenges in junior experts and senior experts list. Similarly "Professional culture" is the most commonly agreed intercultural challenge in intermediate and senior expert's list. The two hypotheses that were observed are given below:

Null hypothesis (H0): There is no difference among the intercultural challenges across different expert's level.

Alternative hypothesis (H1): There is a significant difference among the intercultural challenges across different expert's level.

As it is evident form Table 5 that none of the intercultural challenges have value of 'p' less than 0.05. Therefore we accept the null hypotheses (H0) which means that there is no significant difference among the intercultural challenges based on different expert's level.

4.1.3. Intercultural Challenges for OSDO Vendors Based on Company Size

The whole sample size i.e. 41 responses from the experts were divided into two categories based on company size: 'Small' and 'Medium & Large'. We combined medium and large size companies because we got very few responses from large size companies.

Our results shows that more than 66% of the respondents in small companies and more than 65% of the respondents in 'medium & large' companies agreed that the identified intercultural challenges are confronted by vendors in OSDO relationships. The percentages of various intercultural challenges based on company size are given below:

Table 6 shows that "organizational culture" – 100% and "communication style" – 100% in small companies and "response to time" in medium & large companies are the most agreed intercultural challenges.

"Language and language proficiency" – 91% and "organizational culture" – 91% are the 2nd most agreed intercultural challenge in small companies. Similarly medium & large companies also consider "language and language proficiency" – 96% as the 2nd most significant intercultural challenge for OSDO vendors.

In small companies "difference in social behaviour" and "education system" whereas "difference in social behaviour" in medium & large companies are the most disagreed intercultural challenges.

Similarly 16% of the small company's respondents and 10% of the medium & large company's respondent are neutral about the identified intercultural challenges.

As it is clear for the above results that "language and language proficiency" are the most commonly agreed and "difference in social behaviour" are the most commonly disagreed intercultural challenges in both sizes of companies. The two hypotheses that were observed are given below:

Null hypothesis (H0): There is no difference among the intercultural challenges based on different company sizes.

Alternative hypothesis (H1): There is a significant difference among the intercultural challenges based on different company sizes.

We can see form Table 6 that only one intercultural challenge i.e. "organizational culture" has chi square value of 'p' less than 0.05. Therefore, alternative hypotheses (H1) is accepted

Table 6. Summary of intercultural challenges based on different company sizes.

S. No.	Intercultural challenges	Expert Responses = 41						Chi Square Test (Linear-by-Linear association ∝ = 0.05), df=1	
		Small (N = 12)			Medium & Large (N = 29)				
		A	DA	NS	A	DA	NS	X^2	P
1	Language and language proficiency	11	0	1	28	1	0	0.105	0.746
2	National culture	10	1	1	21	6	2	1.084	0.298
3	Organizational culture	12	0	0	26	2	1	4.329	0.037
4	Professional culture	10	0	2	26	1	2	1.015	0.314
5	Response to time	9	1	2	29	0	0	0.022	0.882
6	Difference in mutual understanding	11	0	1	25	3	1	3.608	0.057
7	Attitude towards authority	10	1	1	23	3	3	0.189	0.664
8	Difference in social behavior	9	2	1	19	7	3	0.477	0.490
9	Different Work ethics	10	1	1	24	4	1	0.274	0.601
10	Education system	8	2	2	24	2	3	0.272	0.602
11	Communication style	12	0	0	26	2	1	0.409	0.523

Table 7. Summary of intercultural challenges based on expert's job position.

S. No.	Intercultural challenges	Expert Responses = 41						Chi Square Test (Linear-by-Linear association ∝ = 0.05), df=1	
		Developers (N = 30)			Managers (N = 11)				
		A	DA	NS	A	DA	NS	X^2	P
1	Language and language proficiency	29	0	1	10	1	0	2.073	0.150
2	National culture	25	3	2	6	4	1	5.372	0.020
3	Organizational culture	29	1	0	9	1	1	1.849	0.174
4	Professional culture	25	1	4	11	0	0	0.279	0.597
5	Response to time	27	1	2	11	0	0	0.312	0.576
6	Difference in mutual understanding	29	1	0	7	2	2	0.699	0.403
7	Attitude towards authority	25	3	2	8	1	2	0.561	0.454
8	Difference in social behavior	21	6	3	7	3	1	1.084	0.298
9	Different Work ethics	24	4	2	10	1	0	0.001	0.973
10	Education system	22	2	4	10	0	1	2.922	0.087
11	Communication style	28	1	1	10	1	0	1.360	0.244

for the intercultural challenge i.e. "organizational culture". The alternative hypotheses formulated for "organizational culture" is given below:

> "Organizational culture" is the most agreed intercultural challenge in small but 3rd most agreed in 'medium & large' companies.

Only significant difference, i.e., "organizational culture" across the company's size is shown in Table 6.

4.1.4. Intercultural challenges for OSDO vendors based on expert's position

All the 41 responses we got form different experts are divided into two categories based on their job positions: developers and managers. Developer's category consists of front end, back end developers and manager's category consists of managers, team leads, and analysts. More than 70% of the developers and more than 54% of the

managers are agree with importance of all the intercultural challenges. The percentages of various intercultural challenges across the two job positions are given below:

According to our results "language and language proficiency" – 96% and "organizational culture" – 96% in developer's list whereas "professional culture" – 100% and "response to time" – 100% in manager's list are the most agreed intercultural challenges.

"Communication style" – 93% is the 2nd most agreed intercultural challenge in developer's list. Similarly "language and language proficiency", "different work ethics", "education system" and "communication style" are the 2nd most agreed i.e. 90% intercultural challenges in manager's list.

In disagreed list (DA), "difference in social behaviour" – 20% and "national culture" – 36% are the most disagreed intercultural challenges in developer's and manager's lists respectively.

13% of the developers and 18% of the managers are not sure about the intercultural challenges as shown in Table 7.

From the above analysis it is clear the "language and language proficiency" is the most commonly agreed intercultural challenge in both types of job positions. The two hypotheses that were observed are given below:

Null hypothesis (H0): There is no difference among the intercultural challenges based on expert's job position.

Alternative hypothesis (H1): There is a significant difference among the intercultural challenges based on expert's job position.

Table 7 shows that only one intercultural challenge i.e. "national culture" has 'p' value less than 0.05. It means that there is a significant difference for "national culture" across different expert's job positions. The alternative hypotheses formulated for "national culture" is given below:

"National culture" is the most agreed intercultural challenge in developer's list and least agreed intercultural challenge in manager's list.

The significant difference is shown in Table 7 for national culture.

5. SUMMARY OF FINDINGS

Intercultural challenges confronted by vendors in OSDO relationships have been identified through empirical study. Vendor organizations need to address these intercultural challenges properly in order to establish long lasting relationships with the client organizations. Critical intercultural challenges have been identified via the following criteria:

If an intercultural challenge is strongly agreed by >= 50% of the experts then we consider that intercultural challenge as a critical intercultural challenge.

Other researchers have also used the same criterion [21]. However, researchers can specify their own criteria in order to select the criticality of identified intercultural challenges.

For RQ1, using the aforementioned criterion we have identified that all the intercultural challenges are critical for OSDO relationships as depicted in Table 3. All the intercultural challenges have frequency greater than 50% which shows the importance of all these challenge in OSDO relationships. In order to achieve success in OSDO relationships with the clients we recommend vendors to properly address all the listed intercultural challenges.

Using the above criterion we have identified that all the intercultural challenges are critical for RQ2, RQ3, RQ4 and RQ5. It shows the importance of these intercultural challenges in OSDO relationships. For RQ2 we identified two significant differences i.e. "organizational culture" and "communication style". National companies

are mostly agreed with these two intercultural challenges whereas in in multinational companies both of these intercultural challenges are the 3rd most agreed intercultural challenges. For RQ3 we identified no significant difference among the intercultural challenges based on expert's experience. For RQ4 using the above criterion we identified only one significant difference, i.e., "organizational culture". "Organizational culture" is the most agreed intercultural challenge in small but the 3rd most agreed in 'medium & large' companies. Similarly we identified only one significant difference for RQ5 i.e. "national culture". "National culture" is the most agreed intercultural challenge in the developer's list and least agreed intercultural challenge in the manager's list.

6. LIMITATIONS

Construct validity is concerned with whether or not the measurement scales represent the attributes being measured. This research used attributes that were taken from our previous research project [16]. The participants' replies show that the considered attributes were relevant to their work. Evaluation of the results can be accomplished through internal validity. The outcomes of the pilot studies provide a satisfactory level of internal validity as the variables involved in our study were taken from widespread literature review and piloting of questions. External validity is related with the generalisation of the outcomes to environments other than the one in which the preliminary study was conducted [32]. We gathered results from 41 experts in total, both national and international, which ensures the external validity; however we cannot argue that all other experts other than the respondents from these countries would agree with these challenges, we believe that they provide a representative sample.

Questionnaire survey method has limitation, that is, the respondents are given a list of possible intercultural challenges and are enquired to select the challenges confronted by vendors in OSDO relationships. This limits the respondents to the given list of challenges and they only focus on the provided list. We asked the respondents to mention any other intercultural challenge if they know other than those already given in the questionnaire. However, like other many researchers (e.g. [33-35,37-39]), we are sure about our results because they are collected from a wide span of experts and practitioners working in OSDO industry. Moreover, experiences of experts were explored independently and without the researcher's suggestions.

7. CONCLUSIONS AND FUTURE WORK

Intercultural challenges faced by vendors have been investigated via empirical study in this research. Properly addressing these intercultural challenges will lead OSDO vendor organizations to successful and long lasting relationships with their clients. Our findings indicate that all the intercultural challenges are critical and important for the OSDO relationships as all the practitioners in the sample strongly agreed with these challenges.

The main objective of this research is to provide a bunch of information to the software development outsourcing vendors to assist them to successfully address intercultural challenges and establish effective relationships with their clients. We propose vendor organizations to emphasis on frequently mentioned challenges as depicted in Table 3 (RQ1) in general. Vendors working with different kinds of organizations (national and multinational) are advised to emphasis on the frequently mentioned intercultural challenges in Table 4 (RQ2). In order to know the experiences of junior, intermediate and senior-level experts, vendors should emphasis on the frequently mentioned challenges identified in Table 5 (RQ3). Similarly vendors undertaking outsourcing with different sizes of organizations (Small, Medium and Large) are advised to emphasis on the frequently mentioned challenges identified in

Table 6 (RQ4).

In case any vendors who want to know the experiences of developers and managers then they should emphasis on the frequently mentioned challenges as depicted in Table 7 (RQ5). We have planned to work on the following goals in future:

To conduct research on each intercultural challenge independently

To identify practices/mitigation advice for addressing each of the identified critical intercultural challenge via empirical study.

Intercultural challenges Mitigation Model (ICCMM) is the ultimate goal of this research study. The empirical study conducted in this research contributes to the 2nd phase of the ICCMM. The proposed structure of the ICCMM has been published [36]. ICCMM will assist vendors in addressing the identified intercultural challenges and managing their relationships with the clients.

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Research Article

Navigation Control of a Multi-Functional Eye Robot

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Abstract: The advancement in robotic field is enhanced rigorously in the past few decades. Robots are being used in different fields of science as well as warfare. The research shows that in the near future, robots would be able to serve in fighting wars. Different countries and their armies have already deployed several military robots. However, there exist some drawbacks of robots like their inefficiency and inability to work under abnormal conditions. Ascent of artificial intelligence may resolve this issue in the coming future. The main focus of this paper is to provide a low cost and long range most efficient mechanical as well as software design of an Eye Robot. Using a blend of robotics and image processing with an addition of artificial intelligence path navigation techniques, this project is designed and implemented by controlling the robot (including robotic arm and camera) through a 2.4 GHz RF module manually. Autonomous function of the robot includes navigation based on the path assigned to the robot. The path is drawn on a VB based application and then transferred to the robot wirelessly or through serial port. A Wi-Fi based Optical Character Recognition (OCR) implemented video streamingcan also be observed at remote devices like laptops.

Keywords: Eye robot, artificial intelligence, UGV, optical character recognition, auto and manual navigation

1. INTRODUCTION

The speedy and extraordinary advancement in the field of robotics is exceptional from the last few decades which causing the scientists overthink to design such reliable and power efficient robots. In areas, where humans can't approach, robots can reach. Military robots provide the facility of bomb diffuser or weapon carriage. An unmanned ground aerial vehicle can give a "birds-eye-view" of territories of military troops. MIDARS [1] is a four-wheeled car type robot, which has few cameras, radar and a firearm. It is used for preprogrammed or random patrols across a military base and other government installations. If it detects any kind of movement in unauthorized areas, it generates alarms. The remote instructor can then command the robot that it can ignore the interrupt, or handle the intruder itself. In emergency conditions, it can also provide camera manipulations and views.

Canadarm or SSRMS, a Space Shuttle Remote Manipulator System [2] is an example of robotic arm which has multi degree of freedom. The special function of this robot is to perform inspections of space shuttle using a specially deployed boom with sensors and cameras attached at the end effector, retrieval maneuvers from the cargo bay of space shuttle and satellite deployment. The hardware of Canadarm proves the significance of robotics in Space missions as shown in Fig. 1.

Fig. 1. Canadarm space terminal [2].

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The Curiosity rover is depicted in Fig. 2 [3], sent on planet Mars has a robotic arm mounted on it. Such robots are specifically designed for space exploring missions, inspection of the land of different planets and for the coverage of space complexities.

Fig. 2. Curiosity rover on planet Mars [3].

In the near future, evolution of Military and Space robots will ensure the facilities like the applications of medical robots. These robots would be able to help in carrying the deceased and wounded soldiers off the battlefield and also will be able to use as prosthetics for troops who are injured and have their limbs amputated.

Multifunctional Eye Robot is basically a type of advanced unmanned ground vehicle (UGV). In a broader sense, it can be any piece of mechanized equipment which can be classified as follows:

Modes of locomotion

Types of control systems

Intended operating areas range

The idea of this project is to develop and design such a UGV explained above. The scope of this project is not restricted in only domain, as it can be deployed in various environments like reconnaissance, search and rescue, border patrol and surveillance, active combat situations, stealth combat operations and many more. The equipment used in it is safe to handle, less costly, reliable and efficient. The cost of fabricating a UGV is approximately $90-100. This is much cheaper than commercial models which are mostly above $300 for the whole working system. This project, however, is only a proof of concept product that is able to complete as many objectives as those commercially available UGVs can and therefore if we consider the price of UGV, it is reasonably acceptable.

The rest of the paper is divided as follows: Section 2 describes the unmanned ground vehicles (UGV), Section 3 covers the design features of the multifunctional eye robot, Section 4 describes the hardware deployed, Section 5 shows the schematic diagram and prototype of the robot, Section 6-7 illustrate the automatic/manual control of the robot and Section 8 concludes the paper.

2. UNMANNED GROUND VEHICLE (UGV)

UGVs like the under discussion robot, find their applications in modern robotics, power plant inspection, space missions and military. The first ever UGV introduced in the world was the USSR developed Tele-tank, which was a machine gun-armed tank type robot. It was controlled by radio from another tank, which was used against Finland in a war. The British developed their tanks in 1941, which were the radio controlled version of their Infantry Tanks known as “Black Prince” robot. So far, several studies for designing UGVs in modern robotics have been reported [4]. Smuda et al. [5] provide vast information about the use of Stereo Vision used in UGVs for the effective working at the time of night. The work is first to show that the stereo vision could also be practical in UGVs because of its non-emissive, non-scanning and non-mechanical properties. Matthies et al. [6] show the significance of Distributive Architecture for Mobile Navigation (DAMN) UGVs. DAMN provides the feasible solution of a robot to follow path and avoid obstacles by sending votes to a command arbitration module. Asynchronous actions are performed by the system and it is responsible for sending its output to the arbiter at particular speed for that specific action. Herbert et al. [7] shows the Velocity transformation techniques used in MUGVs (Military Unmanned Ground Vehicles) and control of direction and driving velocity. The work shows

quite resemblance of these UGVs with the project but the new thing is to ensure auto navigation of the robot by development of App. It's like machines (computer or laptops) controls machines (robots).

Some of the major advantages of UGVs that have made them so popular and significant part of each country's defense strategy today are;

Safety
High access
No loss of life
High speed

The applications of UGVs emerge in any core of military and civil areas are shown in Fig. 3. Currently, Army and Navy are the largest users of unmanned ground vehicles, while Air Forces are making drones that can be controlled or may work more efficiently, it operated in autonomous mode. The threat of encountering chemical and biological weapons in World War III conflicts continues which makes the use of advanced UGVs more significant.

Fig. 3. Diverse and vast advantages of UGVs.

3. DESIGN FEATURES OF THE ROBOT

This paper presents a low cost valuable hardware module for the navigation of a robot in both Autonomous and Manual ways and long range efficient control with video streaming as well as surveillance. It also provides the basic idea of OCR using Multithreading The principal design features of the hardware module are summarized as follows:

It is cheaper and flexible design as compared to the other military robots.

The system can be ungraded under the need and support of advanced robotics techniques. OCR techniques can be improved and made more efficient. Although the response time of robot is already fast but with the availability of strong internet, it can be further improved.

It is flexible and dynamic design.

Battery provides almost 30 to 45 minutes backup. Robot is operated on very low power for its all operations.

All types of alarms or any other interrupts generated by robot can be incorporated and monitored from any location.

In the design of robot, following techniques have been deployed.

3.1. Spy Camera

A camera of common Android based cell phone is used for the video streaming and spying purpose. Its function resembles as Close Circuitry Television (CCTV) networks. Internet-based CCTV flourished in the society due to the expansion of the Internet [8]. The communication channel in the CCTV structure is either wire or wireless network. The crime prevention is now regularly monitored and controlled by the use of CCTV. An application 'CloudCam' is installed in the mobile phone which uses the camera of phone and generates an IP address. Similarly, an application is designed in VB (visual basic) in Microsoft Visual Studio. The IP generated by CloudCam is given to the VB app, and it starts streaming through Wi-Fi and any web browser. This is how, we can monitor the movement of robot or we can use it as spy camera. The basic components for the spying CCTV are the inspection camera of cell phone, image control server for images and video monitoring which is generated by CloudCam, access control server for identification and remote devices like cell phones or laptops.

3.2. SONAR Sensor

Ultrasonic or SONAR sensors are widely used to avoid obstacles. When something, intentionally or unintentionally comes in the path of SONAR oriented robot, what decision it should take? Depending upon the type of hurdle, the programmer must tell the robot that either it should stop moving forward or it should turn left or right. Over the past decade, Autonomous Robot navigation in assistance with Sonar has been the system of research. Initially, Sonar sensor was heralded as a basic and less costly solution of mobile navigation problems, because it enhances the response time and directly gives the range information at user friendly level. However, besides these pros, most scientists would rate the performance of Sonar dissatisfactory [9]. But as far as hurdles detection or distance prediction is concerned, it gives the optimal solution.

3.3. Basic Components

Apart from basic structure, a Robotic Arm is also mounted on the robot which performs drop and carriage functions. Following components are used in the design and implementation of robot:

Arduino Mega 2560 microcontroller.
Basic driving tank type structure.
A Robotic Arm with three degrees of freedom.
2.4 GHz 8 channel RF Module (XP8103).
Orange 9 Channel Receiver.
Two DC 14V gear motors for driving purpose.
Relay based H-Bridge circuit for direction control.
Two DC 14V gear motors for Robotic Arm movement.
A Jaw with Servo motor mounted on it for catch and drop.
Sonar sensor.
L293D QUADRUPLE HALF-H DRIVERS IC for Arm motors.
16x2 LCD display.
4 cell 14.8V, 4000mAh, 35-70C discharge Li-Po battery.
5V battery bank.
LEDs, connectors, buttons and other miscellaneous hardware.

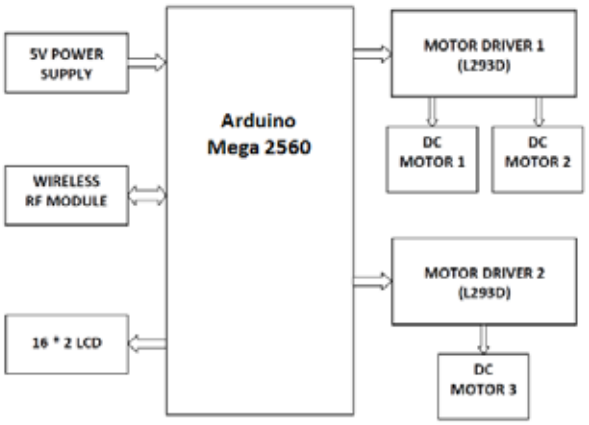

Fig. 4. Block diagram of robotic control unit.

Interfaces of Robotic Arm Unit and microcontroller are shown in Fig. 4. Arduino Mega 2560 works on 5V, while the RF module works on 10.8V, which have a 2.4 GHz frequency range. Physically, for the driving purposes, two DC gear motor are used. These motor work on 14-12V. For direction control, we'll be needing a DC motor driver, which is being designed using relays and Opto-couplers. And to drive the Robotic Arm in multiple directions, we'll be needing a DC motor driver IC called as L293D. The IC drives two motors at a time. The IC has an internal protection suit, just in case to avoid the back EMF generated by the motors when they change their directions. Free Wheeling Diodes are also integrated in the circuit which also gives the protection against back EMF. We have used 16x2 LCD which can be used to check the output of different modules that are interfaced with the microcontroller. Thus, for the better optical vision of the project, checking command lines, and monitoring the output of different modules, LCD plays a vital role.

4. HARDWARE DESCRIPTION

4.1. Arduino Mega 2560 Microcontroller

Arduino Mega 2560 board (Fig. 5) has been featured as the main microprocessor board in this

project. It is an open source electrically configured environment, which is based on user friendly and easy-to-use hardware and software. It is basically used for different sensors by controlling lights, motors assembly and other actuators. It has the following specifications:

- ☐ 5V Operating Voltage
- ☐ 8kB Static RAM
- ☐ 256kB Flash Memory
- ☐ A/DC and D/AC Functions
- ☐ 70 I/O Pins
- ☐ 40 Digital Pins
- ☐ 14 Pins with PWM as Output
- ☐ 16 Analog Pins

Fig. 5. Arduino mega 2560.

4.2. Robotic Arm Assembly

The base of the robotic arm assembly (Fig. 6) is made of aluminum metal while the other part of the arm is made of acrylic material. The robotic arm has a two-fingered gripper hand at the end. The robotic arm has 3 degrees of freedom in it. Two degrees of freedom (at the shoulder part and at the elbow one) have simple brushless DC motors for their operation, while, the gripper hand is controlled through a servo motor [10].

Fig. 6. Robotic arm assembly.

4.3. RF Module and Orange Receiver

A 2.4 GHz, XP8103 radio frequency module (Fig. 7) is used to control the movements of robot and the robotic arm assembly. The module used has a vast operating range of about 2-.5 kilometers and is being used to control 9 channels at maximum. Its operating voltage are 10.8 V. The module acts as information transmitter for communication of signals. A multi-voltage charging adaptor is with this module as an accessory.

Fig. 7. 2.4 GHz RF module.

An Orange receiver (Fig. 8) is used for communicating the channels of RF module with Arduino microprocessor board. The receiver used can control at a maximum of 9 channels. Orange Rx is manufactured using the PCBs which have same impedance with signal stability facility and long range scenario which is advanced as compared to previous products.

Fig. 8. Nine channel orange receiver.

4.4. Battery

A Li-Po (Lithium Polymer) (Fig. 9) is a pouch format battery with rechargeable capacity of lithium ions. These batteries come in a soft

package which no matter lacks in rigidity but makes them lighter. The main battery source used in this project is the 14.8 V rechargeable Li-Po (Lithium Polymer) battery. It has 4 cells in it that give a cumulative voltage of 14.8 V. This battery has about 4000 mAH current producing capability.

Fig. 9. Li-Po battery 14.8V.

4.5. H-Bridge Driver circuit and L293D Driver IC

Basic H-Bridge circuit (Fig. 10) is shown in the following figure which is designed by using relays, transistors and opto-isolators. The bridge is used for the two ways driving purpose of motors.

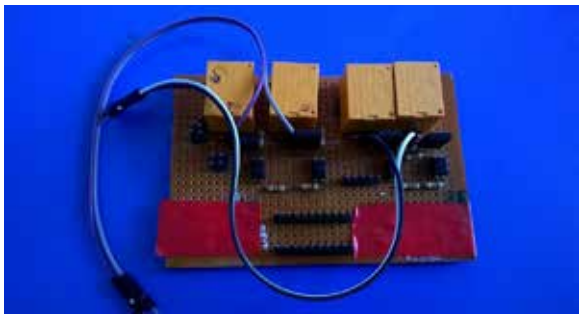

Fig. 10. H-Bridge circuit using relays.

The L293D is a quadrature half H-bridge driver IC (Fig. 11). It is designed to provide bidirectional current of 1A and the voltage ranges from 5V to 36V [14].

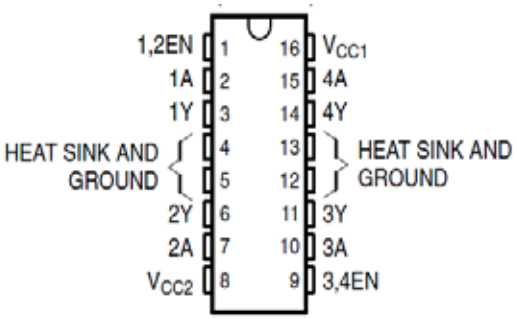

Fig. 11. Driver IC L293D.

5. PROTOTYPE AND DESIGNED CIRCUITRY

The Proteussimulation or the schematic diagram of the project is shown in Fig. 12. The assembling is in such a way that the main control unit or the brain of project is Arduino Mega 2560, which manages all the signals.

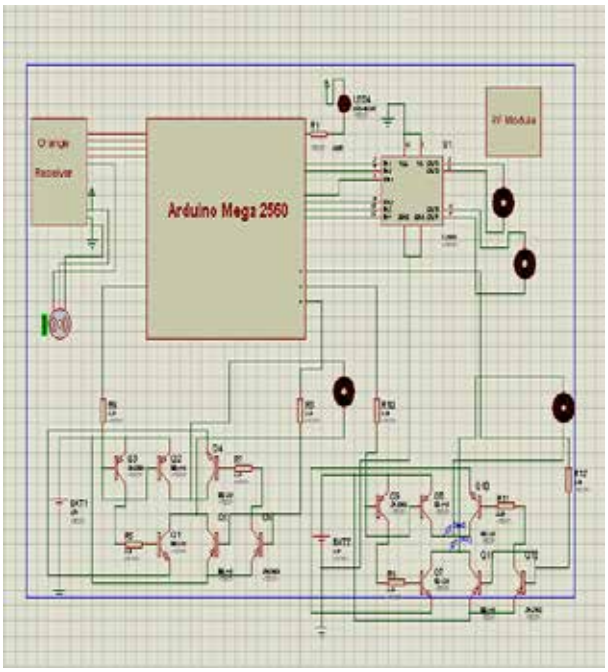

Fig. 12. Drive control circuit for robot**.**

The status of the hardware can be visualized with the help of different LCD mounted on the structure. LCD gives the indication of different types of communication and certain action or response by the microcontroller. A complete assembled robot looks like as in Fig. 13.

Fig. 13. Multifunctional eye robot.

6. AUTONOMOUS FUNCTION OF ROBOT

An application with GUI (Fig. 14) is developed in Visual Basic (VB) which performs the following two major functions.

First it shows the video streaming through the IP address entered into it, if the IP is correct. Moreover, it shows the machine-encoded text from the streaming by performing its OCR.

Secondly it has a portion at which the end user can draw a path. The robot follows that exact path in real time which is being drawn on this app.

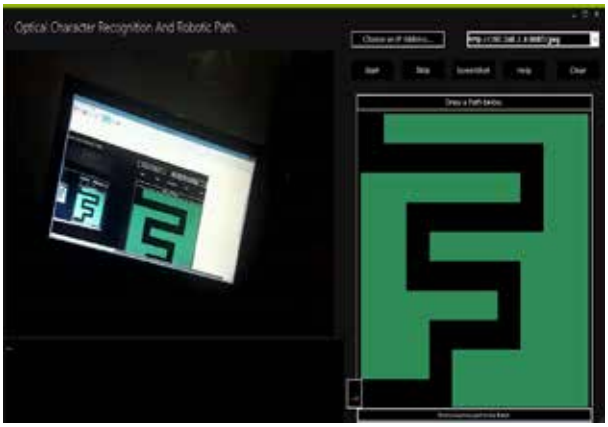

Fig. 14. Application GUI.
(Optical Character Recognition and Robotic Path)

6.1. OCR Technique

OCR (Optical Character Recognition) is a useful technique, in which, images of typewritten or the printed text is converted into machine encoded text by means of mechanical or electrical approaches. It finds its applications in different fields of data entry like from printed paper data records, passport documents, computerized receipts, business cards, mail, printouts of static-data invoices, bank statements or any suitable documentation. OCR is a vast field of research to recognize patterns, AI (Artificial Intelligence) and computer visions. Different kinds of software are used for the implementation of OCR technique. The libraries of OCR can be found directly on internet like TESSERACT or one can build one's own algorithm.

This technology can be used for the navigation of robot. Robot decisions like either it should move FORWARD or BACK, LEFT or RIGHT, STOP can be manipulated through OCR. To implement this technique physically, we place a signboard in the environment as a landmark to decide the next destination of the robot. This signboard tells the robot to take decisions such as it can perform key functions like, the detection of signboard or its identification.

In power plants or in space fields, where optimization or inspection is required, Autonomous navigation of mobile robots in wide areas requires such different signboards with unique patterns. Colored signboards are also used when there is a clear field of view [11]. As far as military applications are concerned, this robot has pretty much resemblance with RHex – Devours Rough Terrain (Fig. 15 [12]) which has a sealed body, making it fully operational in swampy conditions. This type of robots find their uses in the vast field of military as they are able to be controlled remotely from a control unit. Physical appearance may differ but can be modified according to the conditions. Cameras provide better front and rear views from the robot.

Fig. 15. RHex – Devours rough terrain.

6.2. Path Drawing on the Application

Some autonomous robots, in which human inventions are not necessary, are demanded in various applications like military environment navigation, etc. The robots must be intelligent enough to reach their designed destination. It is a key process to design a proper path for the robot so that it could avoid obstacles and reach its end

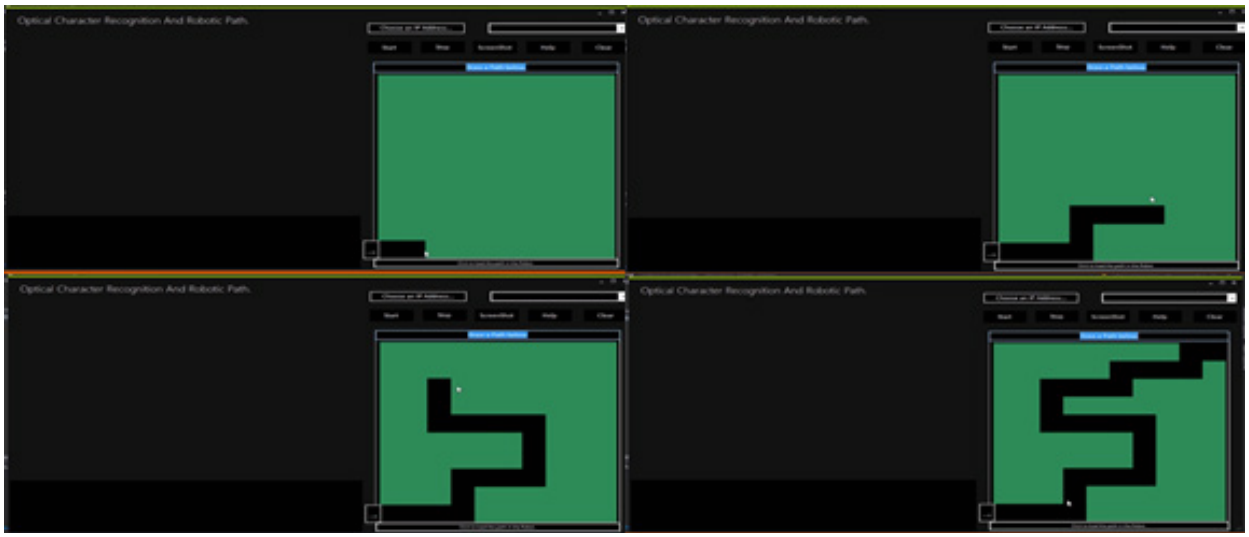

Fig. 16. Drawing a path on OCR app.

point significantly. Thus planning the path carefully is essential in mobile robots as their basic purpose is to find the best shortest and collision-free path up to target point and that must be in accordance of some standards like distance, time and energy. Distance and time are mainly the points under consideration [13]. So keeping that in view, the application is designed in such a way that it has a specific portion at which user can draw any combination of black boxes leading to a correct path and how does the robot follow that path accordingly is shown in Fig. 16.

Application also contains a decoding algorithm which decodes the drawn path and gives the distances along both X and Y axis in numerical values (Fig. 17). These values are then sent to robot and microcontroller then take decisions on the basis of these values that how long the robot should move or it should turn left, right or stop. The path can either be sent wirelessly like through Zigbee Module, Bluetooth or through Serial Port. After the path is sent, the robot starts navigation autonomously, detects hurdles through Sonar sensor and avoid them, take turns according to the decoded path values and streams the video output (Fig. 17).

7. MANUAL FUNCTION OF ROBOT

The robot can also be controlled manually. For that purpose, a 2.4 GHz 8 channel RF module along with a 9 channel Orange receiver is used. The receiver is attached to Arduino board. As long

Fig. 17. The robot following a selective pattern of assigned path.

Fig. 18. Movement of robotic arm during Pick and Drop of an object.

Fig. 19. How Cloud Cam works and the output is displayed at the left laptop.

as a signal being sensed on any pin, the robot keeps on moving accordingly. Similarly, all three degrees of freedom of robotic arm (Fig. 18) and camera are controlled via this RF module. The robotic arm moves according to the signals sent by wireless module as explained in Fig. 19.

8. CONCLUSIONS

This paper explains a methodology for the navigation and locomotion of a robot through a path, drawn on an app and fed to it wirelessly. A better and efficient design in modern robotics is the output of this research work, based on Autonomous and Manual navigation of Multifunctional Eye Robot. The OCR deployed video streaming over Wi-Fi (which is carried out using Multithreading in our coding) and long range control over Robot now will reduce the response time in the event of both war or peace and elevate performance of the Space and Military Robots and eventually the profit.

We evaluated the robot through different phases and tests and carried some rigorous and heavy objects through that robotic arm. Additional work is needed to enable the robotic arm to carry heavy objects smoothly. This model is implemented to integrate wireless communication in a wide range robot, which can stream instant video output regarding the surveillance. Video output or snapshots are recorded and observed lately even when the person is cut off completely from the system and having no way to access the system for monitoring purpose. More work is needed to determine the usefulness of these measures.

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Research Article

Single versus Multi-step Non-Rigid Medical Image Registration of 3D Medical Images

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Abstract: Multi-model medical image registration is very important in medical image analysis and computer assisted surgery. Accuracy and speed are the two crucial factor of any registration algorithm. A Fast Radial Basis Function algorithm for non-rigid medical image registration with improved accuracy is presented in this article. The accuracy of the technique is improved by converting the one-step registration algorithm to multi-step i.e. three-step registration algorithm. The global transformation accuracy of this technique has been evaluated by using two different anatomical landmarks sets. The former is to calculate the model parameters, and the later is used to assess registration accuracy. Finally, we demonstrate that the multi-step technique yields better accuracy (using NMI) as compared to the one-step approach and target registration errors of about 2.91mm on the registration of CT with its synthetically deformed version obtained from the Vanderbilt database. Our study shows that the multi-step fast RBF based registration is more effective in recovering larger deformation and do kept transformation smoothness than the one-step fast RBF based registration.

Keywords: Medical image registration, deformations, radial basis functions, computer assisted surgery, radiotherapy

1. BACKGROUND

Research done so far on non-rigid medical image registration methods for radiotherapy indicates that it gives better results than rigid registration. Non-rigid registration techniques used in radiotherapy are usually divided into two main categories: feature based [1] and intensity based [2]. Feature based techniques require the identification (either manually or partially automated) of a sparse set of corresponding feature points, contours or even surfaces between images, to map one image onto the other. Therefore, it is usually tedious and prone to errors due to manual involvement in locating corresponding features. This often happened in 3D medical image registration where a large number of corresponding anatomical landmark points needs to be identified. On the other hand, intensity based techniques directly operate on image intensity values but require optimization criteria like mutual information (MI) to find the best possible mapping. It is also subject to intensity variations caused by different imaging artefacts. Such methods are accurate but computationally expensive. In landmark based techniques, a single

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misplaced landmark point results into unrealistic deformations in certain situations where large number of accurate anatomical point landmarks placement is difficult. Unlike intensity based registration methods, landmark based registration is less dependent on the underlying image content and need to have a set of reliable corresponding anatomical point landmarks. However, defining a set of large number of anatomical point landmark across two images is time consuming, prone to errors and also needs expert knowledge of the area. This makes the whole registration process complicated but also need expert knowledge.

In order to improve the accuracy and robustness of the deformable method we have proposed a multi-step fast RBF based registration technique and compare its results to the single step fast RBF based registration method. In this paper, we present a non-rigid, feature based registration method aimed at pre- or intra-operative registration of medical images during radiotherapy or surgery. Therefore, the method needs to be fast whilst maintaining acceptable accuracy. The method employs radial basis functions (RBFs), and more specifically the biharmonic spline (BHS), to define a non-linear mapping functions between images to be registered.

In our previous work [3, 4], we developed a point-based algorithm for fast medical registration using RBFs and showed that the warp speed reduced to less than a minute for a size 256^3 dataset (CT/MRI) of the Vanderbilt Database using 8-44 manually defined landmarks. During experiments, it is ob- served that the biharmonic spline (BHS) is the most optimum and theoretically correct RBF function to use in 3D instead of the widely used and the 'popular' thin-plate spline, which is only optimal in 2D. Our proposed work shows that the multi-step fast RBF based registration is more effective and robust in recovering larger deformation and insensitive to the parameters used during registration than the one-step fast RBF based registration.

2. METHODS AND ALGORITHMS

2.1. Fast Radial Basis Functions Technique

The Radial Basis Function (RBF) technique [5] is one of the most widely used technique to approximate or interpolate data scattered in more than one dimensions. The purpose of interpolation is to approximate a real-valued function $f(\mathrm{x})$ over a finite set of values $f = (f_1, \ldots, f_N)$ at the distinct points $X = \{\mathrm{x}_1, \ldots, \mathrm{x}_N\} \subset \mathbf{R}^d$. In similar situation, one chooses an RBF, $s(\mathrm{x})$, for representing such approximations, normally of the following general form:

$$s(\mathrm{x}_i) = p(\mathrm{x}_i) + \sum_{i=1}^{N} \lambda_i \varphi(\|\mathrm{x} - \mathrm{x}_i\|), \mathrm{x} \in \mathbf{R}^d \qquad (1)$$

Where $p(\mathrm{x})$ is a polynomial, λ_i is a real-valued weight[1] ϕ is the (radial) basis function and $\|\mathrm{x} - \mathrm{x}_i\| = r$ is the Euclidean distance between x and x_i. So, an RBF might be defined as a weighted sum of a radially-symmetric basis function, added together with a polynomial term.

The basis function ϕ can take several forms, but three of them have a common property of minimizing specific quantities of energy [1], which makes them suitable for use in 2D and 3D non-rigid medical image registration techniques. Rohr [1] further shows that the biharmonic spline (BHS): $\phi(r) = r$ and the thin-plate spline (TPS): $\phi(r) = r^2 \log r$, both minimize a bending energy potential of order two in three and two dimensional space respectively. Thus to warp 3D image data, the BHS is therefore the choice to be preferred. Rowland et al. [6] confirmed its theoretical optimality in 3D as shown by Rohr experimentally.

Rowland et al. [6] rewritten the Equation 1 without the linear polynomial part (for sake of

[1] The λ weights are determined in the 'calculation' step using a least mean squares approach. This step is followed by the 'evaluation' step which applies the RBF to (usually) all voxels. The latter step is much more time-consuming than the former.

clarity), and extend it to 3D for evaluation of $i = 1 \ldots m$ evaluation points/voxels (targets) represented by the target vector x_i, after having found the spline parameters λ_j for $j = 1 \ldots n$ landmarks represented by the source (landmark) vector y_j:

$$s(\mathrm{x}_i) = \sum_{j=0}^{n} \lambda(\mathrm{y}_j)\varphi(\left\|\mathrm{x}_i - \mathrm{y}_j\right\|), i = 0,\ldots,m \qquad (2)$$

Livne and Wright [7] described a new technique for fast multilevel evaluation of RBF expansions. The main idea of the fast RBF technique is to represent a smooth RBF, ϕ, accurately on a regular coarse grid having few nodes as compare to the full voxel set and thus the expensive summation in Equation 2 need to be performed only at these few nodes while the remaining voxel values can finally be determined using a less expensive formulation based on the values calculated for the surrounding nodes. Unlike the grid based approach by Levin et al. [8], it is the RBF coefficients that are interpolated within the grid and not the intensity values of the voxels. The main principle of the fast RBF technique is to encapsulate source and target points in separate grids of size H. It results in a two stage process conversion of the RBF in Equation 2. The first stage replaced the original **source** points with their corresponding grid points by using a centered ***p***th order tensor product interpolation:

$$\varphi(\left\|\mathrm{x}_i - Y_{\mathrm{J}}\right\|) = \sum_{j:J_k \in \sigma_j^{(k)}} \omega_{jJ_3}\omega_{jJ_3}\omega_{jJ_3}\varphi(\left\|\mathrm{x}_i - Y_{(J_3,J_2,J_1)}\right\|) \qquad (3)$$

where $j = 0, 1, \ldots., \mathrm{n}$ and for dimension $\mathrm{k} = 1, 2, 3$:

$\sigma_j^{(k)} := \{J_k : \left\|Y_{J_k}^{(k)} - y_j^{(k)}\right\| < pH/2\}$, where $\omega_{j\,J_k}$ are the new centered ***p***th order interpolation weights from the coarse $Y_{J_k}^{(k)}$ centres $y_j^{(k)}$ to the landmark positions. The second stage replaced the original **target** points with their corresponding grid points using the same approach:

$$\varphi(\left\|x_i - Y_{\mathrm{J}}\right\|) = \sum_{I_k \in \bar{\sigma}_i^{(k)}} \bar{\omega}_{I_3}\bar{\omega}_{I_2}\bar{\omega}_{I_1}\varphi(\left\|X_{(I_3,I_2,I_1)} - Y_{\mathrm{J}}\right\|) \qquad (4)$$

where $i = 0, 1, \ldots, m$, $\mathbf{J} = (J_1\, J_2, J_3)$, and for dimension $k = 1, 2, 3$: $\bar{\sigma}_i^{(k)} := \{I_k : \left\|X_{I_k}^{(k)} - x_i^{(k)}\right\| < pH/2\}$,

where $\bar{\omega}_{I_k}$ are the centered pth-order interpolation weights from the coarse evaluation point $X_{I_k}^{(k)}$ to the level h (original image grid size) evaluation point $x_i^{(k)}$. The method used to distribute the known RBF coefficients $\lambda(\mathbf{y}j)$ at each landmark position to the surrounding nodes of grid $\mathbf{Y}$ is called *anterpolation*. Further in depth detail of the technique in 1D and 2D can be found in [7] and its 3D extension in [9].

2.2. Multi-step Registration Using Fast RBF

In order to avoid cross-over of structures (unrealistic deformation) during large deformation recovery using landmark based registration, we proposed the multi- step approach with an affordable computation time instead of solving a tight topological preservation map. This is just like divide and conquer rule to recover large deformation while keeping locality of transformation.

Initially, a few corresponding landmarks are selected in both images which roughly represents the corresponding deformation from one image to the other. Registration using the source and target landmarks directly is the one-step fast RBF registration technique but sometimes results into unrealistic deformation due to violation of transformation locality. In order to minimize this unrealistic deformation, we used multi-step fast RBF technique. Each step of our multi-step approach is the application of single-step fast RBF method. We introduced programmatically new virtual landmarks between the source and target landmarks as shown in Fig. 1.

The new virtual point landmarks are not the actual landmarks placed in the images but produced through coding and used to minimize distances between the source and intermediate landmarks to make the transformation local and topology preserved using the fast RBF

registration equation. The final step of the multi-step fast RBF technique uses the same target landmarks identified in the image by the operator.

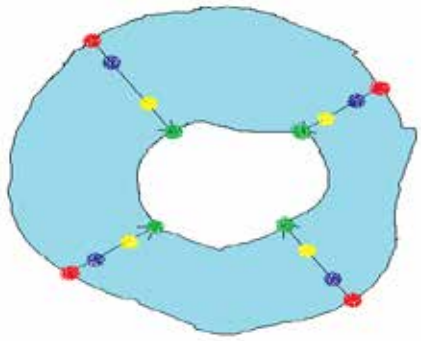

Fig. 1. A 2D representation of the proposed multi-step fast RBF registration approach using two intermediate virtual point landmarks (blue and yellow dots). The red and green dots (source and target landmarks) with the curves represent the source and target image, respectively.

Our multi-step fast RBF method first uses the source (red) and the nearest virtual landmarks (blue) for registration, then the previous virtual landmarks (blue) are considered as source landmarks and used for registration to the next virtual landmarks (yellow). This process is repeated till the final virtual land- marks (yellow in this case) are registered to the target landmarks (black). If the number of the virtual landmarks set is n the registration steps will be $n + 1$. The displacement field for every point in each step is calculated using the one-step fast RBF registration equation in the corresponding region of interest and accumulated to get the final displacement field from source to target image.

2.3. Performance Metric

To access the accuracy of our technique, we use the following two performance metrics:

2.3.1. Target Registration Error (TRE)

The TRE is the RMS error between the homologous validation landmarks after registration. To help the evaluation of global accuracy of registration we developed a set of well defined validation anatomical landmarks.

2.3.2. Normalized mutual Information (NMI)

As the NMI metric (Studholme et al. [10]) is suited to both mono-modal and multi-modal scenarios, we use this metric for image similarity measurement. In many cases it is more stable as compared to mutual information (MI) [11] and the Mattes mutual information (MMI). This metric is overlap invariant, which means that it does not depend on the degree of overlap of the two images and has an optimal value of 2.0 and a minimum value of 1.0.

The registration method was implemented using C++ programming language. All the tests were executed on an Intel Athlon Pentium IV (2.8 GHz) notebook.

3. RESULTS AND DISCUSSION

3.1. Single-step Verses Multi-Step Fast RBF Registration

The number of steps in the multi-step fast RBF registration technique is first specified by the operator which depends on the distances between source and target landmarks. For large deformation recovery, three or four step method is appropriate. In our experiments, we used the real image data obtained from the Vanderbilt database, also known as retrospective image registration evaluation (RIRE) project [12]. Though, this project is design specifically for evaluation of rigid registration techniques using fiducial markers as gold standard. It provides an online access to researchers around the globe for testing their techniques. The data base is also suitable for evaluation of non rigid registration methods as well. First, we deform the CT data using a set of manually defined 9 landmark pairs and BHS based transformation. The role of the set of landmark pairs were reversed and the one-step and multi-step algorithms were then applied to warp the deformed CT *back* to its unwarped equivalent (the ground truth) using a backward mapping approach and the BHS spline as a basis function. This allows us to compare the NMI's of a

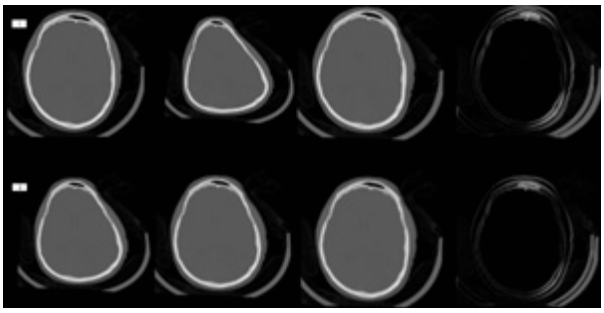

Fig. 2. Row 1 shows corresponding transverse slices from the full resolution CT dataset (Vanderbilt database) of patient P109. The first two images of Row 1 illustrate the original and deformed CT image before registration, while the last two images show corresponding registered and absolute difference images after the direct (single-step) non-rigid fast RBF registration experiment, respectively. On the other hand, the first two images of row 2 indicate the first and second step registration results of the three-step registration, while the last two images show corresponding registered and absolute difference images after the three-step non-rigid fast RBF registration experiment, respectively.

twice deformed dataset with its original, using the latter as the ground truth[2]. We tested both the algorithms using 9 extra landmark pairs for *validation* in conjunction with previously defined 9 *training* (to fit the spline) landmark pairs used for obtaining the deformed CT. For experiment, we downloaded the CT dataset (P109) and resampled them to the size of 256^3 resolution and slice thicknesses of 1mm for registration. We used trilinear interpolation during resampling and during registration as well. Fig. 2 shows the corresponding slices from the one-step direct (row 1) and three-steps (row 2) non rigid fast RBF registration of the CT data with its synthetically deformed CT. The first two images in first row show the corresponding CT (patient P109 of RIRE database) and its deformed version before registration, while the last two images show corresponding registered and absolute difference images after the one-step i.e. direct registration experiment, respectively. In row 2, the first two images indicate the first and second step registration results of the three steps (multi-step) registration, while the last two images show corresponding registered and absolute difference images after the three-step non rigid fast RBF registration experiment, respectively. The deformation recovered using multi- step method (image 3 of row 2) is more reasonable and good as compared to the one-step direct method (image 3 of row 1).

Table 1. Results after applying a BHS basis function based one-step non-rigid fast RBF registration of the CT RIRE data with its synthetically deformed CT. The second column shows the evaluation time of the RBF in seconds. The third column shows the NMI after warping forwards and backwards. The third and final column shows the TRE in mm. which is evaluated on the validation landmarks (forward warp only).

Technique	Eval. Time (Sec)	NMI	TRE (mm)
One-step fast RBF 0.025	67.70	1.258	2.91
Three-step fast RBF 0.025	189.79	1.293	2.91

In this study, we present the non-rigid fast RBF algorithm and extended to multi-step approach for recovery of larger displacement. The multi-step approach gives reasonable results and preserves the transformation locality as compared to the one-step method. The placement of a few pairs of landmarks in source and target images using our developed software took 4 to 8 minutes on average. Table 1 shows the results for the BHS basis function based one-step and multi- step algorithms using CT data, respectively. It indicates the evaluation time and the accuracy measured using NMI and TRE in mm. The best result for the fast RBF method was obtained by setting the *H* parameter to 0.025. The RBF (BHS in this case) calculation time, which is the time required to calculate the spline parameters and of the order of a couple of milliseconds for both the methods (not shown in the table), is negligible as

[2] The TRE error was evaluated for a forward warp only.

compared to the evaluation time (second column), which is the time needed to apply the spline to each voxel of the CT data. The evaluation time (second column) of the one-step and three- step methods are 45s and 135s (45x3), respectively. The calculated TRE (third column) using the *validation*[3] landmarks for both the methods is 2.91*mm* which is due to the same set of *validation* landmark pairs used during experiments. The TRE 2.91mm is greater than the expected (< 2mm) which involve placement error that is difficult to assess but will be smaller if an experienced radiologist has placed the landmarks. Now looking at the accuracy using the NMI metric, we see that the NMI (1.33) of the three-step method is good as compared to the NMI (1.33) of the one-step method. Furthermore, Fig. 3 which shows the visual results of the deformation field obtained using one-step registration (image 3) versus three-step registration (image 4) with same set of landmark pairs.

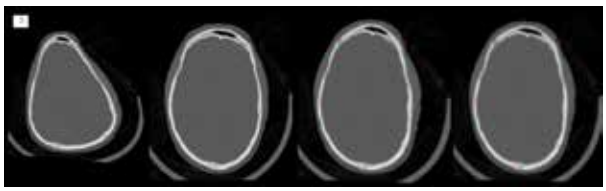

Fig. 3. Selected corresponding transverse slices from the full resolution deformed CT- to-CT dataset from the Vanderbilt database, before (image 1 and 2) the registration experiment, (image 3) the one-step and (image 4) the three-step after the fast RBF registration experiment. The registered CT slice shows numbered landmarks (colour version of the paper): red: training landmark; blue: original test landmark; green: test landmark after registration; the distance between the latter two defines the TRE which should be as minimum as possible.

The three-step registration produced more reasonable mapping of the transformation as compared to the one-step registration mapping. Result of the three-step registration (image 4) also show this, where the bones and other anatomy is better matched with the ground truth data (image 2) as compared to the one-step registration (image 3).

[3] The TRE of the training landmarks is always 0 as the RBF function interpolates the training landmarks.

4. CONCLUSIONS

We have presented an optimised fast non-rigid registration method for medical imaging data using a set of manually identified anatomical landmark pairs. Also, we extend the non-rigid fast RBF algorithm to multi-step approach for recovery of larger displacement. The multi-step approach gave reasonable results and preserves the transformation locality as compared to the one-step method. Keeping the number of steps 3 or 4 in the multi-step algorithm was good enough to produce good results and it made the technique favourable for applications where both speed and accuracy were of importance, such as in image guided surgery (IGS).

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Obituary

Prof. Dr. Muhammad Arshad
(1956–2016)

Prof. Dr. Muhammad Arshad was born on April 1, 1956 in Faisalabad, Pakistan. He did his PhD in Soil Microbiology and Biochemistry from the University of California, Riverside, CA, USA. Dr. Arshad had his entire professional career at University of Agriculture, Faisalabad (UAF) where he served as Director, Institute of Soil and Environmental Sciences; Director, Centre of Agricultural Biochemistry and Biotechnology; Director of Centre for Advance Studies in Applied Genetics and Saline Agriculture; and Senior Tutor. Dr Arshad also served as Editor-in-Chief of Pakistan Journal of Soil Science and as elected President of Soil Science Society of Pakistan, twice, and President of ECP.

Currently, Professor Arshad was serving as Dean, Faculty of Agriculture, University of Agriculture, Faisalabad. Overall, he had more than 37 years experience of teaching and research.

Dr. Arshad had authored/co-authored 4 books (3 published by international publishers and one by national publisher), 11 book chapters, and 155 research articles in foreign refereed journals – with over 300 Impact Factor and more than 2000 citations (ISI Web of Science). He produced 20 PhD scholars as major supervisor and executed 12 research projects, as Principal Investigator, funded by international and national funding agencies.

Innovative scientific contributions and effective writings of Dr. Arshad brought him many national and international honors and awards, like "Best Scientist in Agriculture for the year 2001" by the Pakistan Academy of Sciences; "Best University Teacher for the year 2003" by Higher Education Commission (HEC); National Civil Award *"Tamgha-i-Imtiaz"* 2005 by Government of Pakistan; and best performance shield by the President of Pakistan. Dr. Arshad was honored as Fellow of Soil Science Society of Pakistan in 2006 and by TWAS Prize in Agriculture Sciences for 2007. Recently, he was decorated by HEC as "Distinguished National Professor" for the year 2015-16. He was a recipient of Research Productivity Award throughout. In short, Prof. Arshad was a well recognized scientist in the field of Agriculture and Environment.

In November 2015, Prof. Arshad was elected as Fellow of Pakistan Academy of Sciences; however, he expired prior to his induction as Fellow, which was scheduled towards the end of year 2016. In entire history of the Academy, Prof. Arshad was the second Fellow-elect who left this world prior to induction as Fellow; incidentally, the earlier one was also an agricultural scientist, Dr Abdus Sattar, Chief Scientific Officer & Director of Nuclear Institute for Food & Agriculture (NIFA), Peshawar who was elected in year 2000.

Dr. Arshad was a kind person. He possessed a pleasing personality, and was an amicable colleague and supervisor. In his demise Pakistan has lost a statwart agricultural scientist.

May Allah Almighty bless the departed soul with eternal peace; and give fortitude to his family to bear this irreparable loss! Aameen.

Dr. Abdul Rashid, *FPAS*

Obituary

Dr. Agha Ikram Mohyuddin
(1932–2016)

We are grieved on the sad demise of an eminent scientist and a senior Fellow of the Pakistan Academy of Sciences, Dr. Agha Ikram Mohyuddin, who breathed his last in Islamabad on Wednesday, 10th February, 2016. He was elected Fellow of the Pakistan Academy of Sciences in 1992.

Dr. Agha Ikram Mohyuddin was born in Jullundur, British India on 21 September, 1932. He obtained his BSc in 1953 and MSc (Zoology) in 1956 from University of the Punjab, Lahore. Later, he earned PhD from Queen's University, Kingston, Ontario, Canada.

Dr. Ikram Mohyuddin was one of the founding members of Eco-Conservation Initiative (ECI). He served as Chief Consultant, Integrated, Integrated Pest Management (IPM) Project and Chief Executive, Integrated Pest Management Consultants; Principal Investigator and Coordinator of all the IPM Projects in Pakistan, appointed by Govt. of Pakistan, 1993-1994; Scientist-in-Charge / Director, PARC-IIBC Station, International Institute of Biological Control (IIBC), 1980-1994; Principal Entomologist IIBC, 1960-1979; Lecturer, Zoology Department, Government College, Lahore, 1956-1960; Adviser on IPM of Sugarcane Pests, Gunnung Madu Plantations Bandar Lampung, Sumatra, Indonesia, 1982-1995; Consultant, Malakand Fruit and Vegetable Development Project (Pakistan-Swiss Joint Venture), 1989-1990; Consultant, US-AID Funded Project on IPM of Horticultural Crops in Sri Lanka as Sta of Oregon State University/ Development Alternative Inc., MD, USA, 1990-1992.

Dr. Ikram Mohyuddin was Member, FAO/ UNEP Panel of Experts on IPM, 1982-1986; Member, Panel of Experts, University of Agriculture, Faisalabad ,Pakistan; Member Advisory Committee, Museum of Natural History, Islamabad, 1987-1991. He published Two Books and a Monograph; awarded several Patents and worked on 54 projects in Canada, Uganda, Turkey, Rumania, Bulgaria, Indonesia, Sri Lanka and Sultanate of Oman.

In recognition of his significant contributions in the field of agriculture, Dr. Ikram Mohyuddin was conferred President's Award for Pride of Performance, 1996; Ismail H. Zakria Gold Medal (by Pakistan Society of Sugar Technologists), 1997; Open Gold Medal, Pakistan Academy of Sciences, 1990; Dr. Norman Borlaug Award, by Govt. of Pakistan, 1988; and Ghulam Muhammad A. Fecto Gold Medal, 1986, 1983.

His areas of research were Biological Control and Integrated Pest Management.

Dr. Ikram Mohyuddin possessed a pleasing personality; he was a kind and humble person. In the death of Dr. Ikram Mohyuddin, Pakistan in general and the Pakistan's plant protection scientific community in particular have lost a committed and accomplished research leader.

May the Allah Almighty rest his soul in eternal peace and give fortitude to his family to bear this irreparable loss! Aameen.

Dr. Abdul Rashid, *FPAS*

Proceedings of the Pakistan Academy of Sciences

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DISCUSSION: Provide interpretation of the RESULTS in the light of previous relevant studies, citing published references.

ACKNOWLEDGEMENTS (font size 10)**:** In a brief statement, acknowledge financial support and other assistance.

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a. **Journal Articles** *(Name of journals must be stated in full)*

1. Golding, I. Real time kinetics of gene activity in individual bacteria. *Cell* 123**:** 1025–1036 (2005).
2. Bialek, W. & S. Setayeshgar. Cooperative sensitivity and noise in biochemical signaling. *Physical Review Letters* 100**:** 258–263 (2008).
3. Kay, R.R. & C.R.L. Thompson. Forming patterns in development without morphogen gradients: differentiation and sorting. *Cold Spring Harbor Perspectives in Biology* 1: doi: 10.1101/cshperspect.a001503 (2009).

b. **Books**

4. Luellen, W.R. *Fine-Tuning Your Writing*. Wise Owl Publishing Company, Madison, WI, USA (2001).
5. Alon, U. & D.N. Wegner (Ed.). *An Introduction to Systems Biology: Design Principles of Biological Circuits*. Chapman & Hall/CRC, Boca Raton, FL, USA (2006).

c. **Book Chapters**

6. Sarnthein, M.S. & J.D. Stanford. Basal sauropodomorpha: historical and recent phylogenetic developments. In: *The Northern North Atlantic: A Changing Environment.* Schafer, P.R. & W. Schluter (Ed.), Springer, Berlin, Germany, p. 365–410 (2000).
7. Smolen, J.E. & L.A. Boxer. Functions of Europhiles. In: *Hematology, 4th ed*. Williams, W.J., E. Butler & M.A. Litchman (Ed.), McGraw Hill, New York, USA, p. 103–101 (1991).

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CONTENTS

Volume 53, No. 1, March 2016 **Page**

Research Articles

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