INTELLIGENT TRANSDUCTION FOR RESPONSE SYNTHESIS IN TELEMANIPULATION

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Abstract- A virtual transducer forming technique has been developed with an objective to enhance remote environment perception in tele-robotic systems by adding proximity feel in pre-contact phase during remote manipulation tasks. A fluidics inspired transducer model has been conceived and designed to serve for master side perception creation based on remote robot’s proximity with workspace objects and its dynamics. Robot’s native joint sensors function as primary sensors and active joystick forms the output stage. It induces proximity feel around approachable and unapproachable parts in distinctly different manner. The paper delves in aspects like building re-configurability for varied transducer characteristics formation and tunable force exertion on operator hand for suiting application context and operator choice.

Index terms: proximity, telemanipulator, virtual transducer, force feedback, servo motor, active joystick, remote-perception, operator interface, intelligent sensing
I. INTRODUCTION

Tele-operated systems are used for remote working in hazardous environments like radioactive, biologically contaminated and toxic confines. Operations can be for part manipulation or probing of specimen. Such systems employ a slave robot arm in active workspace for reproducing the motions that are performed on another arm of similar type by the operator located at safe location. Conventional tele-control systems rely on kinesthetic feedback [1]. The ability to feel remote environment at master is dependent on transparency but has an associated problem of stability of system [2]. Such system work in two major regimes of workspace interactions namely ‘in free space’ and ‘in part contact’. For the later regime, transparency is created by using instrumented grasp subsystems capable of tactile sensing in gripper and rebuilding them on master side. In ‘free space regime’ no tactile feedback is available and generally bilateral control give self dynamics based feedback [3][4]. Intelligent transducer can play useful role here. Generally the operator perceives the remote state through visuals only and hits are assessed by human intelligence using vision support [5] and virtual reality[6]. If a sensing method is devised to create ‘closeness perception’ for the remote robot end-effector ‘REE’ then operator can have better feel of remote environment and even feel an impending hit. In ‘tele-probing’ involving surface scan of remote located specimen by contact or near contact type sensors like ultrasonic flaw detectors and eddy-current probes, perception of proximity is highly desired in ‘near-contact’ state as it does not generate any reaction feedback owing to REE’s non contact condition. The objective of this work is to develop a ‘transduction method’ that offers perceivable forms of feedback generation at operator end. Proximity alone is not sufficient parameter to formulate perception and dynamics of REE plays an important role.

II. RELATED WORK

“Virtual fixture” refers to a general class of guidance modes [7][8] that help a robotic manipulator perform a task by limiting its movement into restricted regions and/or influencing its movement along desired paths and prohibit the motion of a robot manipulator into forbidden regions of geometric or configuration space. Spring action have been proposed[9][10] but they are not passive and tend to react on stationary state REE too. Virtual fixtures have limitations. These introduce abrupt changes in machine response and have been treated as hyper plane in software domain for simulation environments serving for operator training. Though, with some specific adaptation, this approach has been applied for on-line force feedback [11] to develop perception of approaching software configured barrier
parts, limitations in fixture shaping arising from consideration of real-time computation burden, lack of framework for their integration into a tele-managed system, and absence of system assisted or automated method of implementation have restricted their use in training applications where it serves as safety curtain to avoid damage from wrong operator action.

III A NEW APPROACH

The desired method must permit motion through it to permit the Robot End Effector ‘REE’ to reach a part in impact constrained manner by enabling human operator with appropriate perception while working in ‘man-in-loop’ type operating scenario. The method must be automation savvy and should avoid introducing instability in control loop by ensuring passive nature, wherein a ‘zero’ REE motion results in null forces on operator side. The general bilateral control for tele-manipulator is complicated and passivity of system needs to be ensured [12][13]. An economical operator support method can be developed by a ‘virtual transducer’ for slave arms working in CAD modelled workspace, as location of the probe in

remote workspace can be determined using kinematic model of the robot and dynamics can be assessed from commands flowing to the slave that define the slave state (fig.1). The proposed transducer develops response parameter ‘RP’ by using modeled impedance on the robotic arm’s approach to a part based on the on-line computed parameters. The transducer is expected to meet several criteria depending on the type of the object REE is in vicinity of.

A. DESIRED TRANSDUCER BEHAVIOR FOR APPROACHABLE OBJECTS-

An approachable body in workspace opposes REE motion towards it in a manner depicted in figure 2. V is velocity of approach towards the approachable body and F represents response parameter ‘RP’ which mostly is implied as opposition force to the REE but in some
implementation can be audio-visual effect. Its magnitude is represented by width W. Higher the FEE velocity towards the approachable body higher is the discouragement to the REE operator at master end. This also implies that an approachable body can be reached by REE at very slow speed. It is equivalent to gently touching without impact and is desirable.

B. DESIRABLE BEHAVIOR FOR UNAPPROACHABLE OBJECTS

Unlike an approachable body an unapproachable body must not allow contact at all. An REE reaching with low velocity too must find high opposition and transducer response must match it. FEE move in close vicinity (red zone in figures 2d,2e,2f) develops a high ‘RP’ irrespective of approaching REE velocity. It is important to note that ‘RP’ may be used to generate a real opposing force in some implementation and an operator moving the REE with high velocity will suddenly face high opposition force giving him/her no time to respond as the reaction may be shocking. This must be avoided else control may turn unstable. The close vicinity zone must have a preceding zone that opposes fast approaching REE. The faster REE sees higher ‘F’ similar to that faced in red zone (fig.2f). Operator is dissuaded at such high speed. He has to slowdown for ‘F’ to yield and permit move towards body. Consequently a slowed down motion prepares operator to face high ‘F’ at contact. It also minimizes impact on contact.

C. NEED FOR POSITION SENSITIVITY IN MODEL

A more desirable characteristic of the transducer is shown in figure 3. This behavior has increasing opposition as REE reaches closer to the object. It can simultaneously make the opposing force ‘F’ dependant on nearness to tail of cylinder end, so can serve the dual purpose of supporting creation of a tactile feel of proximity.
IV. FLUIDICS INSPIRED MODEL

A. THE TRANSDUCER MODEL:

Consider fluid motion in a closed piston-cylinder assembly (figure 4). The cylinder has a side branch tube connected at tail end of cylinder through which the fluid can flow back to the head end of the cylinder. The side assembly consisted of one outlet at head end and a single inlet at tail end. A piston pushes the fluid from head end which flows back into the cylinder through the side loop.

![Figure 4, The single bypass cylinder behavior.](image)

To simplify the model we made some assumptions such as no friction between cylinder wall and fluid. Further, we considered no turbulence conditions and the flow to be in laminar regime. Volume flow rate through the cylinder \[\text{14}\] is

\[Q = \frac{(v \pi D^2)}{4}\]  \hspace{1cm} (1)

Where \(v\) = piston velocity, \(D\) = cylinder diameter

Flow resistance of pipe: \(R = \frac{(128 \mu l \pi)}{d^4}\)  \hspace{1cm} (2)

where \(\mu\); fluid viscosity, \(d\); pipe diameter, \(l\); pipe length

Force on piston: \(F = \Delta P \cdot A = Q' \cdot R\)  \hspace{1cm} (3)

\[Q' = \frac{(v \pi D^2)}{4} \cdot \left(\frac{D}{d}\right)^2\]  \hspace{1cm} (4)

Where \(\Delta P\) is pressure difference between two sides of the piston, \(Q'\) is volume flow rate through pipe and \(R\) is flow resistance of the pipe. \(F\) can be rewritten as

\[F = v \cdot \left(\frac{D}{d}\right)^2 \cdot \left(\frac{128 \mu l \pi}{d^4} \cdot \pi D^2 / 4\right)\] \hspace{1cm} (5)

\[F = v \cdot C \cdot \rho\] \hspace{1cm} (6)
Where \( C = (D/d)^2 \), \( \rho = ((128\mu l^4)/(\pi d^4))^{*}(\pi D^2)/4 \). Both \( C \) and \( \rho \) are functions of cylinder dimensions and fluid viscosity respectively and are constant for a given set up, leaving the force \( F \) as a function of velocity. Opposing force \( F \) on cylinder, varies linearly with piston velocity (fig.4c).

\[ F = \nu * (D/d)^2 * (1/(1/\rho_1+1/\rho_2+1/\rho_3 ... 1/\rho_n)) \]

\( \text{(7)} \)

In present example \( n \) is 5. As the piston moves inward in cylinder, return paths keep falling out of the loop. At point 4 (figure 5c) resistance to flow is

\[ \gamma = (1/ (1/\rho_1+1/\rho_2+1/\rho_3+1/\rho_4)) \]

\( \text{(8)} \)

At point 3 (figure 5d) effective \( F \) increases to \( \rho = (1/ (1/\rho_1+1/\rho_2)) \)

and in general at position ‘\( m \)’

\[ \gamma_m = \sum_{n=1}^{m} (1/ (1/\rho(n))) \]

\( \text{(9)} \)

For computation (7) ‘\( n \)’ reduces from a maximum integer value in an implementation to 1 as the piston progresses. Figure 5E shows complete behavior of ‘\( F \)’ for a constant velocity ‘\( \nu \)’ of piston. The model enhances properties of single pass loop back cylinder by adding the
capability to produce object vicinity based increase of ‘F’. A push action on piston at constant speed causes stepped increase at each bypass crossing. The effect is more enhanced for piston moving at higher velocity (fig. 6). It retains the property of velocity dependence of earlier version. The position dependant change in F can be used to generate perceivable increase of opposing force ‘F’ with nearness to a body part while approaching it and the property can be used to ensure reaching body without high impact.

(ii) Touch Inhibition by transducer:

If the end of cylinder is reached it faces rigid obstruction. The same effect can be achieved by adding an attribute in software implementation that assigns ‘F’ a preset high value without using computation (7) of model. The model is then complete with all requirements indicated in figure 2f.

C. MODELED TRANSDUCER’S FUNCTION:

The model can be imagined as an arrangement placed with the close-end of cylinder touching the specimen part and the axis of cylinder aligned with normal to the surface (fig. 6a). A REE approaching the specimen has to push the piston to reach the body surface. Such an arrangement achieves velocity based opposition to REE move in neighborhood of body. It hinders move along ‘II’ in figure 6b, which has high velocity, but permits approach at a very low speed reducing risk of damage by REE impact as evident for move along path ‘I’. This behavior is important for probing tasks where the REE carrying the sensor-head has to work in close neighborhood of the specimen and touch it too. ‘F’ computed by (7) is treated as ‘RP’ for developing perceivable effect to operator. The stepped variations (9) in $\gamma_m$ is
preferred by some users as the resulting sharp change in F at positions 1, 2, 3 etc, in figure 6, cause easily perceptible feel of F. A smoothened F too can be mathematically formulated by using interpolations to intermediate positions.

IV. TRANSDUCER FORMATION

Transducer function is formed in two phases. In pre-run phase, a desired model is formed by choosing n, d and l. Resulting impedances $\gamma_n$ are associated to the virtual space around the part in workspace. In this arrangement, $\gamma_1$ is the impedance closest to part surface and is assigned from the last segment of the cylinder and $\gamma_5$ is assigned 5th from first segment (fig. 5). It is maintained by virtual transducer as property data (fig. 7a).

In run time the REE position is computed from the kinematics model using the present joint parameters being followed by slave arm. This being the REE position in workspace, corresponding $\gamma$ value is identified and retrieved from stored property data. The probe velocity ‘v’ is computed from discrete time stamped positions at time intervals or from velocity sensors on slave robot arm, applicable F i.e. ‘RP’ is computed by (7). RP is converted in physical form by using servo motor operating in current control mode[15][16][17]. Since it produces controlled torque, it offers force-feel on active joystick AJS as opposition.

Figure 6. a (left): Conceptual piston-cylinder assembly attachment to an object’s outer surface. b (right): ‘F’ developed by multi-pass loopback cylinder for progressive piston push and its dependence on piston velocity.
A. DESIRED CHARACTERISTICS OF FORM-CONVERTER:

In overall transducer formation, the real feedback is a combination of force-feel created by AJS and audible signals (fig 7-b). The AJS must be well balanced to appear passive at null position. It must have low inertia and avoid gear losses of torque by employing direct gearless ‘motor at joint configuration’ so that full force generated by transducer action reaches the handle for force feedback (fig 8). The torque demand signal vs. torque output characteristic of the motors must be linear and torque versus gain slope should be programmable as the gain selection is dependent on the sensor output dynamic range.

(i) Stable characteristic and low inertia

For large force on hand by AJS, geared configurations too can be used. But friction in gear introduces nonlinearity. Friction being highly unstable phenomena owing to it’s dependence on lubrication that changes with working temperature and the long term variation in organic characteristics like viscosity and layer adherence on metal surfaces, is impossible to model accurately. In addition the inertia in gearbox introduces a delay in response generation on operator’s hand. This is highly detrimental in present scenario as the REE in close vicinity of object has high sensitivity of force generation and operator may be considerably off the
mark in sensing the synthesized reaction. The gear must be low back lash type in construction else it introduces a dead band in operator input around ‘0’ condition in operator input which occurs in condition of restart. It is dealt with in a later section. Experiments in this work have used non-geread configuration.

(ii) Compactness and energy efficiency

Operator interface in real systems need to generate high force-feedback only at contact with unapproachable object as an unusual condition. The infrequent need for high force on operator hand is met by using torque controlled motors with moderate continuous duty rating but intermittent high (up to 300%) torque delivery (fig.9a,10a). The motor and controller combination should be energy efficient [18][19][20] for ensuring compactness and achieving low inertia of overall assembly.

(iii) Tunable force exertion

For RP conversion to ‘force-on hand’, the servo motor and controller combination is configured in ‘torque-mode’ and operating sensitivity is designed as illustrated in figures 9 and 10. For example, choosing (I) permits rated torque generation only in entire piston stroke and (II) sets use of 50% range for proximity zone and 200% torque on object contact. Type (I) is suited for manipulated objects while (II) and (III) are suited for non-contactable objects. Type (III) offers coarse force feel in vicinity and rigid opposition on contact and serves best with high torque motor (fig.10) for obstacles and fixtures in workspace.

Figure 9a: θ axis command Voltage-Torque Characteristics. b: θ motor characteristics in torque control mode
Active joystick (AJS) has been formed using 100 W motor on $\theta$ axis and 400 W motor on $\phi$ axis. Though $\phi$ axis has increased inertia relative to 100 W motor, it is less than that of a motor-gear combination and has zero back lash thus eliminating all problems attributed to geared-axes. Axes are adequately counter-balanced. As a consequence the force felt by

Figure 11  a (left): The Active Joystick built in laboratory. b: Force feel on operator hand

the hand (fig.11) is purely owing to the motor torques only. The $\theta$ axis has 0.32 N-m torque capability up to 50rps with torque constant 0.36N-m/A, and $\phi$ axis has torque 1.27 N-m up to 50rps with torque constant 0.49N-m/A. Experiments were done for both exclusively. The AJS developed in laboratory (fig 11) employs light wooden handle and aluminum chassis to keep inertia low and uses counterweights to attain balance. Motor at joint without gear is the key feature. The operating characteristics are set in experiments here along the dotted operating lines (fig. 9b.10b).
V EXPERIMENTAL PERFORMANCE

An experimental set-up is built using a tele-controlled set up that uses 5 DOF robot [21] of Cartesian type (fig.12a). The REE can be oriented in space by rotations in two mutually orthogonal plane and located by 3 axis Cartesian positioning in a workspace of size 1000x1000x600mm. The robot and associated control set-up is equipped with joint position and velocity sensing electronics [22]. The servo system executes all motions with commanded speed in closed loop controlled manner[23][24]. During a single axis motion execution, joint position and velocity are sensed and computations (fig7b) are done to form RP as per model. RP signal are applied to AJS for torque generation (fig 12b). The problem of placing aforementioned model in REE’s motions path while approaching a body is solved by associating ρ values in workspace model (fig. 7a) which is discrete position representation in the 3D Cartesian work space analogous to ‘pixel’ in 2D image representations and referred as volume element or ‘voxels’. The voxels also hold local property of this tiny space. The property can be of varied types and their use have yielded fast response in diverse methods like hit detection and robot path finding in 3D space [25][26]. A solid cube placed in workspace appears as in figure 7a. In 3D space of the robot ‘Z’ (height) is kept fixed at 300 mm, \( \gamma_m \) values in the 2D plane are assigned by treating it as 2D array and REE motion is permitted in this plane. In experiments, X motion occurs at controlled speeds along constant ‘Y’ within coded zone.

![Image](image_url)

Figure (left)12a, 5 DOF Cartesian robot experimental set-up. Figure (right)12b. A single axis test setup in the experiment. AJC is joystick controller, time stamping is used for unified temporal data referencing.

A. RESPONSE PARAMETER ‘RP’ GENERATION:

In the experiments, slave motor (5DOF robot) worked on velocity control mode. Velocity control signal to the controller was formed by 14 bit accuracy D/A output and updated at
100 Hz. Shaft encoder tracking was achieved by the slave joint controller and time stamped position was acquired. For high speed approaches, the object surface was used as data coded limit and real object was removed for avoiding inadvertent damage during experiments.

(i) Regular size ‘G’ based model

The probe robot arm was moved along a fixed ‘Y’ at different constant velocities which were sensed by the robot joint sensors in real time. The ‘F’ values generated by the model are shown in figure 13. ‘RP’ developed by the system for same conditions but constant accelerations and constant deceleration are shown in figure 13b and 13c.

![Figure 13](image)

Figure 13 ‘RP’ generated at different seeds of REE for transducer model coded as per (10)

(ii) Effect of variation of ‘gap’ between bypasses

The parameter ‘G’ i.e. gap(fig.5a) is mapped as ‘k’ (integer) numbers of voxel of length ‘Vx’. Therefore ‘k’ is scale factor between real workspace and model. For k=2, fluid resistance γ forms an array that appears as

\[
\gamma_1, \gamma_1, \gamma_2, \gamma_2, \gamma_3, \gamma_3, \gamma_4, \gamma_4, \ldots, \gamma_{(n-1)}, \gamma_{(n-1)}, \gamma_n, \gamma_n
\]

(10)

The profile is depicted by different color code in figure (14a) and is repeated for a set of Y values for facilitating single axis motion along X axis. If value of gap ‘G’ is reduced then ‘k’ reduces. Lowest value can be k =1. The coding is shown in figure 10a and effect is depicted in figure 11b. The advantage of narrow gap is evident in closer vicinity where a responsive operator reduces speed causing REE slowing down but bypasses being nearer still senses slowdown owing to frequent change of γ rather than change of ‘v’ which may not be appreciable over short travel. An interesting way of enhancing closeness perception is to have gap ‘G’ of different sizes. At periphery of vicinity G can be longer and close to object it can be reduced. For such case the γ_m coding for the same part is as shown in figure 14b. The
resulting ‘RP’ is shown in figure 16c. As REE approaches closer to the object the transducer produces more frequent ‘RP’ change giving feel of increasing proximity by increasing frequency of step changes on AJS.

![Diagram](image)

Figure 14a. Coding for narrow ‘G’;  Fig. 14b. for unequal gap ‘G’

**B. Performance of the transducer**

(i) **Performance for approachable part**

The servo controller of AJS motors provide instantaneous torque proportional signals at monitoring output. For a nominal holding position at 75mm from the AJS shaft, the force appears as in figure 15 for REE motion executed by controller at zero acceleration, constant acceleration and constant deceleration. Tests with narrow regular G as well as varying G too have been conducted (fig16).

![Graphs](image)

Fig.15 Performance of transducer (θ axis) for constant G and fixed, accelerating and decelerating motions.

![Graphs](image)

Figure 16. Effect of changing ‘G’ on force feedback. a; regular gap with k=2, b; regular gap with k=1 and c initially k=2 and later k=1
The AJS produces stepped force opposing operator hand which increases in magnitude with advance of REE towards object. For higher velocity of approach, at same relative distances from object surface it produces higher force magnitude step. On frequency scale the faster move generates increasing frequency of steps. A design with lower G near cylinder end offers relatively faster step occurrence at low velocity too and enhances perception of approach to object more effectively.

(ii) Performance for un-approachable part

An unapproachable part is modeled by coding the last layer adjacent to a part (red in figure 17a) with an additional attribute whose effect is to consider ‘F’ as a predetermined high value rather than as computed by (7). The γm coding for unapproachable part along with blocking layer and F generated for it appear in figure 17a and 17b. Note that such block may cause shock on AJS for fast move but the preceding high opposition by AJS actually prepares the operator for the situation. For a slow move stepped force at block is manageable. Progressively reducing G in design can restore frequency based feel for slow speed too.

![Figure 17 unapproachable part (left) and F generated for it (right)](image)

The ‘RP’ in experiments produced perceivable opposition force to operator’s hand placed at nominal distance of 75 mm from rotation axes in manner expected using M1 on 100% dynamic torque range for approachable objects. For non approachable objects, rigid opposition at conditions equivalent to body contact was not felt adequate at operator’s hand using M1. Operator, if not cautious can force through the opposition. However using M2, perceivable rigid opposition could be formed within 88% of torque range. For constant speed move, generated by computer controlled servo, appreciable stepped changes in force were produced for low speeds when high torque gains were set. But for speeds above 0.3 m/sec. force was high enough to push back inexperienced operator. Response parameter developed here works well (table 1). Individual’s sensitivity being different, range tuning is desirable.
## Table 1: Force Output Performance Of AJC In Intelligent Transducer.

<table>
<thead>
<tr>
<th>Motor</th>
<th>Mode</th>
<th>Control signal (volts)</th>
<th>Torque Usage</th>
<th>Experimental observation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>VICINITY AT NORMAL SPEED</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M1</td>
<td>High Velocity</td>
<td>0 – 3.6 (+/-)</td>
<td>Normal demand</td>
<td>Effective force feedback dependant on vicinity. AJC operation is low inertia, quick response. Transducer action very good. Well suited for delicate manipulation.</td>
</tr>
<tr>
<td></td>
<td>Contact</td>
<td>10.0 (+/-)</td>
<td>Full overdrive (300%)</td>
<td>Distinctly felt contact opposition, operator caution must for not breaking torque limit.</td>
</tr>
<tr>
<td>M2</td>
<td>VICINITY AT NORMAL SPEED</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>High Velocity</td>
<td>0 – 3.8 (+/-)</td>
<td>Normal demand</td>
<td>Effective force feedback dependant on vicinity with wider force range. Transducer action very good. AJC feels heavier on hand</td>
</tr>
<tr>
<td></td>
<td>Contact</td>
<td>10.0 (+/-)</td>
<td>partial overdrive (250%)</td>
<td>Rigid opposition at contact, robust operation against operator error. Well suited for obstacles and non contactable objects</td>
</tr>
</tbody>
</table>

The participating experimenters were permitted to set ‘RP to force ratio’ by adjusting torque gain of M1 or M2 as per their sensitivity. All experimenters perceived the approach phenomenon in spite of not being allowed to see the robot and workspace.

### VI IMPROVEMENT OF OPERATING INTERFACE

The RP maintains passivity in operator controlled motion loop as stopping motion causes $F=0$ condition and operator can hold the robot at place in vicinity of a part. However the operator should continue to perceive vicinity in some way else sudden motion can be initiated by him/her in absence of vicinity feel and in systems having limited bandwidth for feedback, contact with considerable mechanical impact can occur. The AJS formed for converting RP to real force perception using torque motor may have a drawback. For developing significant force on operator hand the torque motor needs to be bigger and hence result in low or at best moderate bandwidth of the force conversion from RP. Solution lies in using $\gamma$ (8) in an ingenious way to form multimode interface at master.

Motivated by multimode interface [28] we form it by feeding tones to a audio speaker based on $\gamma$ (figure 13). While the RP is used for developing opposing torque by AJS, $\gamma$ dependent variable frequency audio tone makes the operator aware of relative closeness to the object even when REE is kept standstill by operator.
VII CONCLUSION

Efficacy of the synthesized transducer lies in its capability of distinctly different response creation for manipulated and non approachable objects like workspace construction features and obstacles defined by the task definition in a structured remote work environment. Yielding opposition to operator as well as rigid opposition is feasible in the transduction scheme. The vicinity activation model effectively supports intelligent human-machine interface formation.

The characteristic is tunable by tweaking independently behaving parameters. Spatial variation of bypass gap ‘G’ in non uniform manner can be used to cause more frequent change in the response parameter at closer vicinity and offer improved perception of approach to a body by temporal changes of force which are inherently immune to background noise arising from velocity sensing errors. This illustrates re-configurability of the model. The model is predominantly software implemented and so is highly amenable to automated formation for complex workspaces created by CAD modeled objects. Automated formation has been addressed [29] by imparting motion resistance property in the surrounding space around the modeled version of the real object. This gives a strong sense of relative object approach which is more effective than vision based approaches as a view by itself needs to be augmented with contextual interpretation aid [30][31]. Verification of the method is possible by using a laboratory version slave robot instrumented without interconnect
encumbrance similar to that devised for wireless monitoring of utilities [32] as the wireless sensor networks are evolving with better functionality [33]. The transduction method developed here can also work with interfaces such as the electro-hydraulic type actuators [34] for heavy duty applications. Though the audio feedback is produced in different perception domain, fusion of effects happens in operator brain and the perception is effectively enhanced. The method is attractive for tele-managed probing as well as operator training systems for tele-control.

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