

Intelligent Parametric Visual Thinking System (IPVTS) as a Paradigm for Control Strategies with Time-Delay in Robotics

Review of the NRC project performed by N. Tikhonov in Air Force Research Lab, Wright –
Patterson

STATEMENT OF THE PROBLEM

The objective of this research is to develop better theoretical and practical methods for using virtual reality, image understanding technologies, and conceptual parametric object-oriented design for control strategies in Robotics, algorithms and software that is based on coordinating and adapting the appropriate virtual reality visual display with the appropriate sensory feedback (force, tactile) for modeling high-level descriptions of the sensing of surfaces, shapes, and textures.

The Human Sensory Feedback (HSF) project at the AFRL headed by Dr. Repperger [Repperger et al., 1995, 1997, 2000], captures attention of computer scientists and engineers as a new methodology for building human-robot technology and for the support for many aspects of requirements analysis that simulates an expert in the performance of control tasks.

However the problems of control in Robotics based on human-like control behavior, with the appropriate sensory feedback for a integrated real-time system, are complex and many-sided. During this transformation process the HSF provides automated support for many aspects of virtual reality interfaces using Visual and Haptic rendering based on maintaining consistency between graphical views and algebraic notation of a design [Repperger et al., 1995, 1997, 2000].

Thus engineering methods and procedures that encompass both geometric and non-geometric objects require a level of human-like intelligence for understanding this paradigm, which current methods do not support. Most of the existing systems can execute direct human instructions yet cannot help him in abstract thinking. Considering this analysis, the research objectives of this proposal are:

- To develop theoretical and practical methods of coordinating and adapting the appropriate virtual reality visual display with the appropriate sensory feedback (force,

tactile) in a simulation for robotics using image understanding technologies based on new technology - Intelligent Parametric Visual Thinking System (IPVTS).

- To transform a visual spatial model into a control process algorithm to achieve the required functional properties with optimal characteristics.
- It is necessary to create the IPVTS that has an intelligent human-like engineering methodology where design, geometry, analysis, intelligent control and optimization are combined into a single computational system to aid in engineering design using high-level visual prototyping.

BACKGROUND AND RELEVANCE TO PREVIOUS WORK

The need for investigations of alternative sensory feedback, such as with a Haptic interface, is indicated by being extremely important for adaptive remote control of complex integrated systems. This is because the human hand is a powerful tool through which the human brain interacts with the world [Repperger 1997], [Flanagan 2002]. According to publications [Repperger et al., 1995, 1997, 2000] and other scientists [Flanagan 2002], it is necessary to note that fundamental research in development methods of Haptic interfaces and “virtual force” methodology have significant importance in improving the operator’s ability to observe and control his environment.

The paper [Repperger 1995] addresses adapting the kinematical control for robots and concludes with a review and description of prior work with problems involving dynamics, control, design, the trajectory and speed planning utilizing control, and data flow based on the mathematical model using Denevit-Hartenberg transformation [Repperger 1995]. This paper shows how the seventeen coordinate systems based on Denevit - Hartenberg transformation are used for the formal model of the components orientation. To improve these developments we define the focus for this proposal on intelligent human-robot interface models for generating the global formal graphical universal model based on sensory perception and visual thinking.

In the work [Repperger 1997], it describes how a haptic interface was correlated to the visual scene displayed to the pilots.

Early research in this area has demonstrated certain benefits of using Virtual Reality Systems. In the reference [Floyd 1999], this author has developed the system in which the PHANTOM can interact with the 3D bitmapped virtual environments using the Cellular Automata CAM-8 Modeling. Methods for control in Robotics based on the time delay and the wave variables are described, also, to design the system with high effectiveness. This bitmapped simulation allows the extracted position data and return force data directly with the PHANTOM robotic simulation. It allows the user to create a very universal method of modeling. This is main advantage of this system, but this system has low speed for complex systems and requires a very large computational resource. It should be noted that this system has a lower number of control parameters for the objects involving optimization.

However, it is more important to integrate the bitmapped environment and the discrete dynamical system with a high-level computational system based on a graphic implementation and a combination of heuristics [Tikhonov 2002].

Extending on these works we believe that there is a need for a fundamental work to automatically generate suitable control strategies for robots and position tracking involving complex shape surfaces and textures, such a model has a feature-based visual model in the query using formal graphic specifications and visual thinking.

To improve these developments we define the focus on this proposal based on intelligent human-robot interface models for generating the global formal graphical universal model based on sensory perception and the visual thinking.

Creating of integration mechanisms for IPVTS which will provide the integration including multi-sensory feedback tools, using mathematical modeling and programming languages (C++, Java, Visual Basic.), and other integration formats and databases.

GENERAL METHODOLOGY AND PROCEDURES

Extending the robotics model [Repperger 1995], it is required to develop a new discrete dynamical system (Fig. 1) as high-level computational systems with graphic implementation and a combination of heuristics:

$$\mathbf{G} = [\mathbf{V}, \mathbf{E}, \mathbf{T}(\mathbf{V}), \mathbf{C}(\mathbf{V}), \mathbf{X}_i(\mathbf{V}), \mathbf{Y}_i(\mathbf{V}), \mathbf{Z}_i(\mathbf{V}), \mathbf{A}_i(\mathbf{V}), \mathbf{HF}_i(\mathbf{V}), \mathbf{P}_i(\mathbf{V}), \mathbf{PF}_i(\mathbf{V}), \mathbf{BD}_i(\mathbf{V}), \mathbf{TO}_i(\mathbf{V}), \mathbf{W}_i(\mathbf{V}), \mathbf{PB}_i(\mathbf{V}), \mathbf{G}_i(\mathbf{V}), \mathbf{SB}_i(\mathbf{V})] \quad (1)$$

where a composite node's implementation is the graph \mathbf{G} , \mathbf{V} is the set of vertices of regular lattice associated with edges \mathbf{E} , minimum execution time $\mathbf{T}(\mathbf{V})$ and control constraints $\mathbf{C}(\mathbf{V})$ associated with \mathbf{V} , $\mathbf{X}_i(\mathbf{V})$, $\mathbf{Y}_i(\mathbf{V})$, $\mathbf{Z}_i(\mathbf{V})$ are coordinates of vertices of vectors associated with \mathbf{V} ; homogeneous transformation matrix $\mathbf{A}_i(\mathbf{V})$, heuristic functions and rules $\mathbf{HF}_i(\mathbf{V})$, parametric constraints $\mathbf{P}_i(\mathbf{V})$, parametric function $\mathbf{PF}_i(\mathbf{V})$, feedback function (as bias distance) $\mathbf{BD}_i(\mathbf{V})$, text $\mathbf{TO}_i(\mathbf{V})$; connection weighs, $\mathbf{W}_i(\mathbf{V})$, local feedback function $\mathbf{PB}_i(\mathbf{V})$, genetic code $\mathbf{G}_i(\mathbf{V})$, and optimization criterion $\mathbf{SB}_i(\mathbf{V})$. For example, the relative position and orientation of frame $(\mathbf{XYZ})_i$ with respect to frame $(\mathbf{XYZ})_{i-1}$ (Fig. 1), can now be expressed by a homogeneous transformation matrix $\mathbf{A}_i(\mathbf{V})$ and complex composition matrix $\mathbf{A}_{0i}(\mathbf{V})$ (for representation of the vector $\vec{01}$) which describes the composition of the translation matrix \mathbf{T}_{0i} , the translation inverse matrix \mathbf{T}_{0i-1} , the rotation matrices, $\mathbf{R}_{X0i}(\alpha)$, $\mathbf{R}_{Y0i}(\beta)$, $\mathbf{R}_{Y0i}(\varphi)$, $\mathbf{R}_{Z0i}(\theta)$, $\mathbf{R}_{Z0i}(\gamma)$ on angles respect to coordinate axes \mathbf{X}_i , \mathbf{Y}_i , \mathbf{Z}_i [Foley , 1996], the inverse rotation matrices $\mathbf{R}_{Z0i-1}(\theta)$, $\mathbf{R}_{Y0i-1}(\varphi)$ and scaling transformation matrix \mathbf{S}_{0i} for arbitrary vector $\vec{01}$ as follows:

$$\mathbf{A}_i(\mathbf{V}) = \mathbf{A}_{0i}(\mathbf{V}) = \mathbf{T}_{0i-1} * \mathbf{R}_{Z0i-1}(\theta) * \mathbf{R}_{Y0i-1}(\varphi) * \mathbf{S}_{0i} * \mathbf{R}_{X0i}(\alpha) * \mathbf{R}_{Y0i}(\beta) * \mathbf{R}_{Z0i}(\gamma) * \mathbf{R}_{Y0i}(\varphi) * \mathbf{R}_{Z0i}(\theta) * \mathbf{T}_{0i} \quad (2)$$

The structure of IPVTS is a tree consisting of atomic and composite nodes (Fig. 1, Fig 2). The IPVTS automatically allows the transform of each formal parameter from graphic specification CAD systems into a primitive vector-prototype of fractal homogeneous neural

network in according with the homogeneous composition the vector transformation matrix $A_m(\mathbf{V})$ based on generated hypergraph model matrix

$$A_m(\mathbf{V}) = A_{01} A_{12} A_{23} \dots \dots \dots A_{(m-1)m} \quad (3)$$

The general concept and procedure of IPVTS (Fig. 1, Fig. 2) consists of the followings steps:

- *create* the intelligent objects with visual information using mechanisms of homogeneous fractal interpreting visual images (Fig. 1, Fig. 2) . This method is based on self-similarity of atomic and composite prototypes and consists in modeling of composite prototypes by several smaller fragments of themselves. The image is sliced in segments of irregular or regular form using the minimum execution time $T(\mathbf{V})$ of prototypes (Fig. 1). During this concept, our approach allows structuring the homogeneous composition transformation matrix (2) $A_1(\mathbf{V})$ and hypergraph model matrix $A_m(\mathbf{V})$ (3) into components which can be executed in parallel as separate standard parametric prototypes (For example, the matrices A_{01} , A_{12} , etc.).

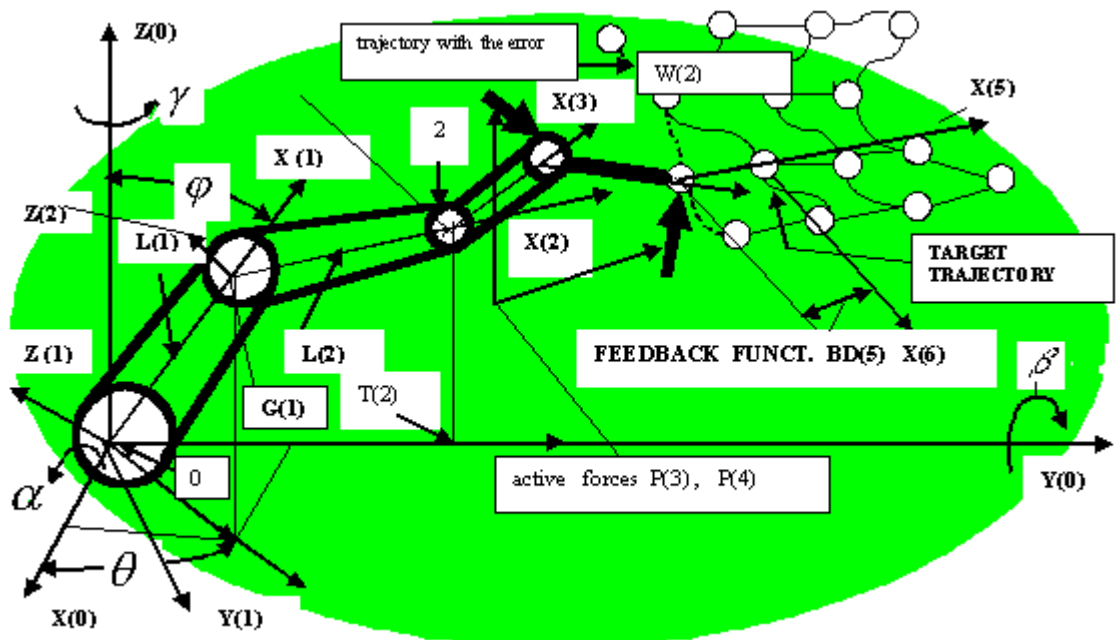


Fig. 1 Functional schema of control strategies for robotics using IPVTS

- *generate* a homogeneous network of nodes, each of which can be of a finite number of V possible states updates in discrete time steps according to the IPVTS model (1) with local identical interaction rule (see Fig. 1, 2);
 - *build* initial 3D or m -vector parametric model based on Geometric Modeling System (Fig. 2) and model (1) with parametric function $\mathbf{PF}_i(\mathbf{V})$ and parametric constraints $\mathbf{P}_i(\mathbf{V})$ (for example the force) using both the IPVTS graphic specification and the full automatic transformation from geometric model or CAD systems;
 - *create* the intelligent objects with visual information using mechanisms of homogeneous fractal interpreting visual images (Fig. 1, Fig. 2). This method is based on self-similarity of atomic and composite prototypes and consists in modeling of composite prototype by several smaller fragments of themselves. The image is sliced into segments of irregular or regular form using the minimum execution time $\mathbf{T}(\mathbf{V})$ of prototypes (Fig. 1). During this concept, our approach allows structuring the homogeneous composition transformation matrix (2) $\mathbf{A}_i(\mathbf{V})$ and hypergraph model matrix $\mathbf{A}_m(\mathbf{V})$ (3) into components which can be executed parallel as separate standard parametric prototypes (For example, the matrices \mathbf{A}_{01} , \mathbf{A}_{12} , etc.).
 - *generate* a homogeneous network of nodes, each of which can be of a finite number of V possible states updates in discrete time steps according to IPVTS model (1) with local identical interaction rule (see Fig. 1, 2);
 - *build* initial 3D or m -vector parametric model based on Geometric Modeling System (Fig. 2) and model (1) with parametric function $\mathbf{PF}_i(\mathbf{V})$ and parametric constraints $\mathbf{P}_i(\mathbf{V})$ (for example the force) using both the IPVTS graphic specification and the fully automatic transformation from the geometric model or CAD systems;
- update* a site of nodes of a homogeneous lattice according to a definite heuristic rule and heuristic functions $\mathbf{HF}_i(\mathbf{V})$ that involve a neighborhood of sites around each one. Global control heuristic for all nodes of a model is a feedback function (bias distance) $\mathbf{BD}_i(\mathbf{V})$ for

transform of the parametric constraints $P_i(\mathbf{V})$ such as dimensions and normal/shear forces

(Fig.1).

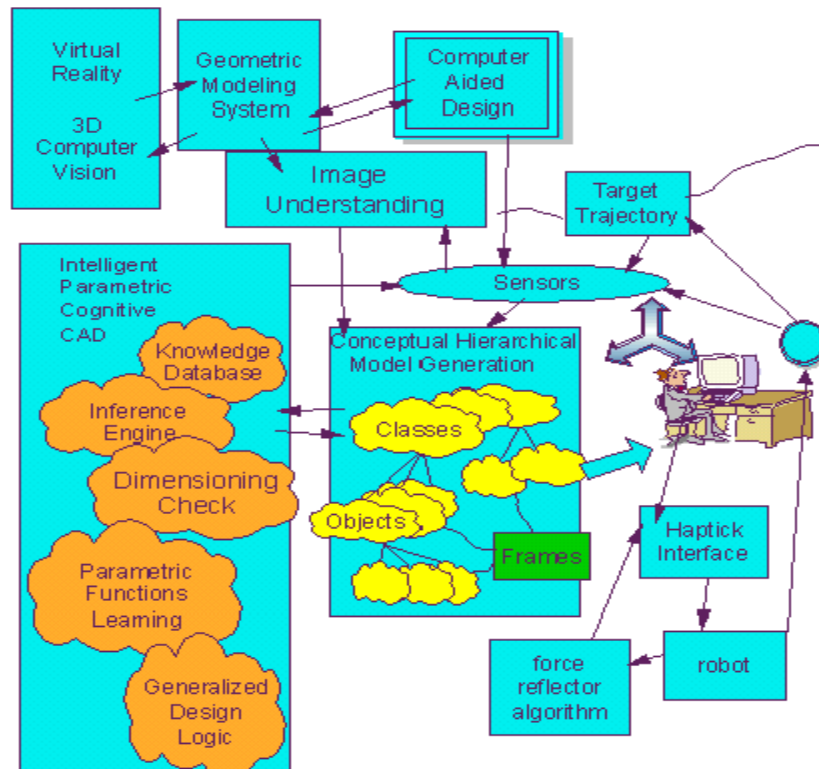


Fig. 2 The human-machine haptic interface based on IPVTS algorithm

- *change* the sites of nodes of a homogeneous lattice according to control constraints $C(\mathbf{V})$, the parametric constraints $P_i(\mathbf{V})$, a definite heuristic rules and heuristic functions $PF_i(\mathbf{V})$ involving the values of its nearest neighbors, where the position of sites around each of the vertices are determined relative to a local system of coordinates. It is implemented as a set of situation-action rules associated with Generalized Design Logic, and Knowledge Database (Fig.2) that implements the local solving method based on triangular systems of neighborhood structures;
- *transform* of the parametric constraints $P_i(\mathbf{V})$ or $C(\mathbf{V})$. IPVTS uses the global control heuristic for all nodes of the model such as a bias distance (feedback) $BD_i(\mathbf{V})$ associated with local system of coordinates from node to node along the edges (Fig.1);
- *determine* and evaluate the several possible parameters of lattices of the neighborhood structures for this step with respect to global structures for this step and global system of

coordinates using both the homogeneous transformation matrix $\mathbf{A}_i(\mathbf{V})$ and heuristic functions $\mathbf{HF}_i(\mathbf{V})$ with learning parametric function of geometric objects (Fig.2);

- *convert* atomic prototypes into many-level concept's system developing the "intelligent" parameterized prototype-classes and prototype-objects using on object-oriented analysis and composition of system from hierarchical modules based on SQL database and knowledge database (Fig. 2.);
- *make* the automatic constraints check with dimensional chains and relationships to the composite prototype;
- *repeat* all consecutive or concurrent steps for all vertices of a network with computing connection weighs $\mathbf{W}_i(\mathbf{V})$, cost weighs $\mathbf{SB}_i(\mathbf{V})$, and genetic code (chromosome) $\mathbf{G}_i(\mathbf{V})$ for search of optimal solutions.

EXPLANATION OF NEW AND UNUSUAL TECHNIQUES

A major difference between the IPVTS methodology and other systems is that it automatically specifies the method requiring parametric automatically coding for a genetic structure of the model, of the sensors and working components that have two styles for rapid prototyping:

- analytically using algebraic notation and formal specification;
- visual with formal parametric geometric representations.

IPVTS allows us to develop a wide variety of learning genetic algorithms created from graphical specifications. This approach has the following advantages over current practice:

- IPVTS is a simple system for very complex behaviors because they have used general and simple rules with heuristic functions $\mathbf{HF}_i(\mathbf{V})$. It allows easily and quickly derived simulations to visualize a m-dimensional space with an n-vector attached to each point in the space in according to physical phenomena.

- It allows the development of a graphical formal specification that is fully associated with the task of learning the parameters, weights and structure of each of these representations for genetic optimization.
- We can sense both normal and shear forces as well as render texture using the PHANTOM robotic systems. We can also generate texture on a joystick and use a number of force reflecting robotic devices to test this theory and practical application of the methodology.

EXPECTED RESULTS AND THEIR SIGNIFICANCE AND APPLICATION.

IPVTS is a simple system that exhibits very complicated behavior using global control strategies, generic rule and heuristics. IPVTS will allow the implementation of the following:

- Image understanding and converting into high-level robotics/ human-machine interface models, which allow us to remove the operators from potential hazardous environments;
- Automatic generating target trajectory, surface shapes and texture and also other control programs from graphic specification using IPVTS;
- Simulating, visualizing and checking constraints of integrated systems such as forces and pressure using the knowledge database more accurately and usually faster than conventional algorithms;
- Dramatically improving both the quality and speed of control tasks for a system of linear, polynomial or transcendental equations instead of the Newton-Raphson method.
- Run Haptic Research based on the reflected force for PHANTOM devices with time delay and employing wave variables to improve situational awareness and operator performance.

The dynamic intelligent parameterization is used, in this system, to provide a great opportunity to transform a visual spatial model into a control process algorithm to achieving the required functional properties with optimal characteristics.

See below the algorithms and mathematical models based on the examples of teleoperation using this system.

ALGORITHM OF BASIC TELEOPERATION

For the virtual reality environment with a virtual force F_e (see Fig 7) the following equations of motion exist for the x axis:

$$F_e = M_e \ddot{x}_e(t) + B_e \dot{x}_e(t) + \zeta_e x_e(t) \quad (12)$$

where $x_e(t)$ denote the displacement of the slave arm in the e environment, $\dot{x}_e(t)$ velocity and $\ddot{x}_e(t)$ acceleration are of the slave arm in the e environment and M_e , B_e and K_e are the inertia, damping, and stiffness, respectively. In this equation, B_e is physical constant that characterizes the transmission line as the damper (friction) in the environment.

Let $F_e = F_s$, resulting in the following equation :

$$F_s = M_s \ddot{x}_s(t) + B_s \dot{x}_s(t) + K_s x_s(t) \quad (13)$$

For a master, we have respectively:

$$F_m = M_m \ddot{x}_m(t) + B_m \dot{x}_m(t) + K_m x_m(t) \quad (14)$$

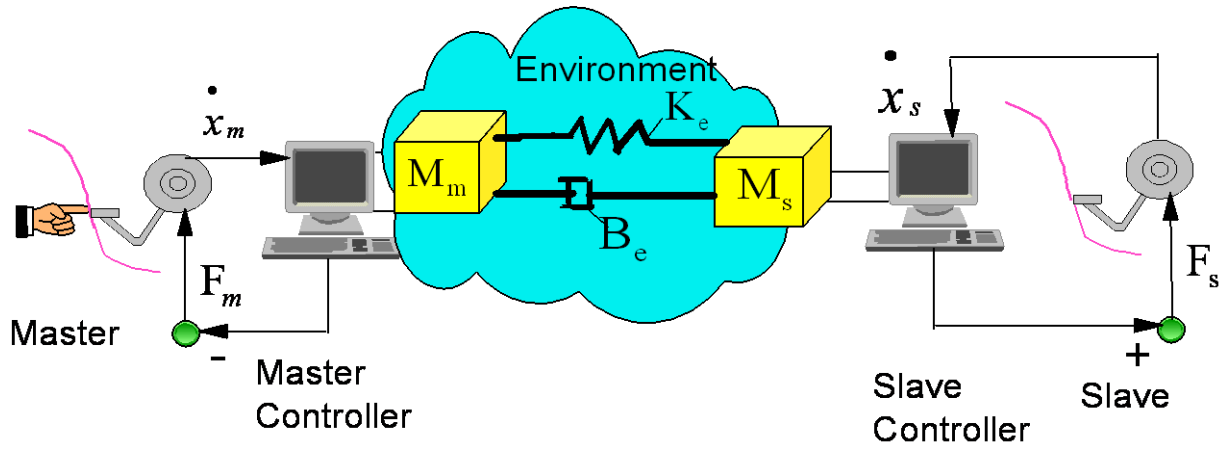


Fig. 7 Basic Teleoperator without Time Delay based on two inertia - M_m , M_s connected via a spring - K_e and damper B_e in the environment.

A bilateral teleoperation system can be represented as a translation dynamic system based on a three dimensional model:

$$F_s = -F_m = M_e [\ddot{x}_m(t) - \ddot{x}_s(t)] + B_e [\dot{x}_m(t) - \dot{x}_s(t)] + K_e [x_m(t) - x_s(t)] \quad (15)$$

where $M_e = M_m = M_s$, $B_e = B_m = B_s$ and $K_e = K_m = K_s$

K_s is the virtual stiffness of the slave, K_e is virtual stiffness and K_m is a stiffness of the operator's hand

$$\begin{aligned} F_{sx} = -F_{mx} &= M_e [\ddot{x}_m(t) - \ddot{x}_s(t)] + B_e [\dot{x}_m(t) - \dot{x}_s(t)] + K_e [x_m(t) - x_s(t)] \\ F_{sy} = -F_{my} &= M_e [\ddot{y}_m(t) - \ddot{y}_s(t)] + B_e [\dot{y}_m(t) - \dot{y}_s(t)] + K_e [y_m(t) - y_s(t)] \end{aligned} \quad (16)$$

$$F_{sz} = -F_{mz} = M_e [\ddot{z}_m(t) - \ddot{z}_s(t)] + B_e [\dot{z}_m(t) - \dot{z}_s(t)] + K_e [z_m(t) - z_s(t)]$$

A bilateral teleoperation system can be represented:

$$\begin{aligned} F_{sx} = -F_{mx} &= -M_e [\ddot{x}_m(t) - \ddot{x}_s(t)] - B_e [\dot{x}_m(t) - \dot{x}_s(t)] - K_e [x_m(t) - x_s(t)] \\ F_{sy} = -F_{my} &= -M_e [\ddot{y}_m(t) - \ddot{y}_s(t)] - B_e [\dot{y}_m(t) - \dot{y}_s(t)] - K_e [y_m(t) - y_s(t)] \\ F_{sz} = -F_{mz} &= -M_e [\ddot{z}_m(t) - \ddot{z}_s(t)] - B_e [\dot{z}_m(t) - \dot{z}_s(t)] - K_e [z_m(t) - z_s(t)]. \end{aligned} \quad (17)$$

The master will reflect the virtual contact force of the slave back to the operator and the slave will follow the position of the master exactly because there is no time delay in this case.

$$\begin{aligned}
 F_{mx} = -F_{sx} &= M_e [\ddot{x}_m(t) - \ddot{x}_s(t)] + B_e [\dot{x}_m(t) - \dot{x}_s(t)] + K_e [x_m(t) - x_s(t)] \\
 F_{my} = -F_{sy} &= M_e [\ddot{y}_m(t) - \ddot{y}_s(t)] + B_e [\dot{y}_m(t) - \dot{y}_s(t)] + K_e [y_m(t) - y_s(t)] \\
 F_{mz} = -F_{sz} &= M_e [\ddot{z}_m(t) - \ddot{z}_s(t)] + B_e [\dot{z}_m(t) - \dot{z}_s(t)] + K_e [z_m(t) - z_s(t)]
 \end{aligned} \tag{18}$$

MODELING OF DYNAMICS AND UNCERTAINTIES BASED ON TRANSFER FUNCTION

Suppose we specify the dynamics in the environment such that

$$G(s) = \frac{\dot{\gamma}_e(s)}{F_e(s)} \tag{45}$$

next we have

$$\dot{x}_e(s) = \dot{\gamma}_e(s) * G(s) \tag{46}$$

where $G(s)$ some stable transfer function. Then the equation (37) will incorporate the reflected wave :

$$\sqrt{2b}v_s(s) = \dot{\gamma}_e(s) - \dot{\gamma}_e(s) \tag{47}$$

$$\sqrt{2b}v_s(s) = \dot{\gamma}_e(s) [F_e(s) * G(s)] - \dot{\gamma}_e(s)$$

(48)

or after the transformations

$$\sqrt{2b}v_s(s) = b_e * F_e(s) * [G(s) - 1] \tag{49}$$

Now we can consider

$$v_m(t) = v_s(t - \tau)$$

and at the master robot :

$$F_m(t) = b \dot{x}_m(t) - \sqrt{2b} * v_m(t)$$

(50)

We wish to design $F_m(t)$ at the master:

$$F_m(t) = b \dot{x}_m(t) - \sqrt{2b} * v_s(t - \tau) \quad (51)$$

then choose

$$F_m(t) = b \dot{x}_m(t) - \sqrt{2b} * b_e * F_e(t - \tau) * [G(s) - 1] \quad (52)$$

therefore we have the $F_m(t)$ force on the master robot that can be controlled, with desired characteristics and the desired transfer functions $G(s)$ using additional elements (an example damper), which are inserted into the P.D. PHANToM controller .

We can control the desired $F_m(t)$ on the master robot by varying the transfer function $G(s)$ using the three dimensional model with the x,y,z axes :

$$\begin{aligned} F_{mx}(t) &= b \dot{x}_m(t) - \sqrt{2b} * b_e * F_{ex}(t - \tau) * [G_x(s) - 1] \\ F_{my}(t) &= b \dot{x}_{my}(t) - \sqrt{2b} * b_e * F_{ey}(t - \tau) * [G_y(s) - 1] \\ F_{mz}(t) &= b \dot{x}_{mz}(t) - \sqrt{2b} * b_e * F_{ez}(t - \tau) * [G_z(s) - 1] \end{aligned} \quad (53)$$

It is very important for optimal design to create the best match of the impedance between the P.D. controller and the wave transmission. We propose, using a layout as shown in Niemeyer's work, (see Fig. 41) for our visual model of the PHANToM robot.

We may add a noise or an uncertainties into the wave variable on slave robot $v_s(t)$.

Suppose that the signal $v(t)$ is the one we wish to track. We want $x_e(t)$ to follow the target in space $v(t)$. The tracking error in this case is desired :

$$x_{error} = v(t) - \dot{x}_e(t) \quad (54)$$

We further use three methods for getting of signal $v(t)$ on our model:

- As a wave with $v(t) = A \sin \omega t$;
- As random signal $v(t)$, this signal is generated by the moving mouse along the x, y (z signal is generated) in time as control events in model;
- As one random signal $v(t)$.

We would like x_{error} to be asymptotically stable such that

$$G(s) = \frac{\dot{x}_e(s)}{F_e(s)} = \text{which implies some stable transfer function (i.e. we have a stable$$

impedance in the environment).

We select $v_s(s)$ in the environment to consist of two terms :

$$\sqrt{2b}v_s(s) = \dot{x}_e(s) - \dot{x}_e(s) = \text{tracking error} + \text{impedance interaction} + \text{noise error} + \text{master}$$

Hence

$$\sqrt{2b}v_s(s) = \dot{x}_e(s) - \dot{x}_e(s) = x_{error}[e^{-\gamma t}] + \eta(t) + \beta_n(t) \quad (55)$$

$$\text{Hence } b_e \dot{x}_e(s) - \dot{x}_e(s) = \gamma(t) + \eta(t) + \beta_n(t)$$

$$\text{Hence } F_m(t) = \dot{x}_m(t) - \sqrt{2b} [v_s(t - \tau)]$$

$$F_m(t) = \dot{x}_m(t) - \sqrt{2b} [\gamma(t - \tau)]$$

$$F_m(t) = \dot{x}_m(t) - \sqrt{2b} [\gamma(t - \tau) + \beta_n(t - \tau) + \eta(t)] \quad (56)$$

$$\text{where } \gamma(t - \tau) = [v_s(t - \tau)]$$

IMPEDANCE MATCHED TELEOPERATOR

In this case, described by Niemeyer, the wave communications acts as a true admittance. It observes forces on both sides and updates the desired motions as needed. Both master and slave are controlled via an impedance matched P.D. controller.

SLAVE AND MASTER CONTACT WITH ENVIRONMENT

Preliminary research with the PHANToM have shown that the time delay in the condition of contact causes a very unstable process. However, to continue this research is needed in more detail with the wave variable method.

FUTURE RESEARCH

Use Wave-Based Teleportation for the PHANToM with integrated IPVTS for different variable parameters changing in wide limits:

- a) wave variables
- b) single variable combinations of both velocity and force data
- c) for large delays with methods including wave impedance matching,
- d) wave filtering and wave controllers
- e) wave reflection
- g) research the Drifting Problem and three Feedback Paths Problem.

We will change these combinations of parameters using the wave controllers based on computer modeling in a real-time system with and without time delays. The possible solutions and conditions of experiments will be utilize into a Knowledge Database. The goal of these experiments is to compare the stability of the control system with the wave variables using the different types of sensory information, for large delays and with methods including wave impedance matching, the wave filtering, and wave controllers.

It allows us to use the advantage of the intelligent m-dimensional parametric control based on IPVTS.

- Run the experiment based on IPVTS together with the PHANToM with a predictor incorporated inside the wave junction.

- Run the experiments for target detection using IPVTS with the PHANToM based on the different types of sensory information and in conjunction with the cues which work together with the intelligent m-dimensional parametric control. Analyze the errors that might occur in the control process. It is desired to use the advantage of the intelligent m-dimensional parametric control based on IPVTS.
- Use Transfer Functions $H(s) = V(s)/U(s)$ to further illustrate in a Visual Model the meaning and behavior of wave variables and systems as criteria for control.
- Create the optimization system in IPVTS for the design Classic Elements in Wave Space for basic controllers such as PHANToM Robot, Haptic Stick, 3D-Audio Computer Controller and Computer Based MEMS Controller.

APPENDIX: Examples for short demonstration of the concepts of IPVTS

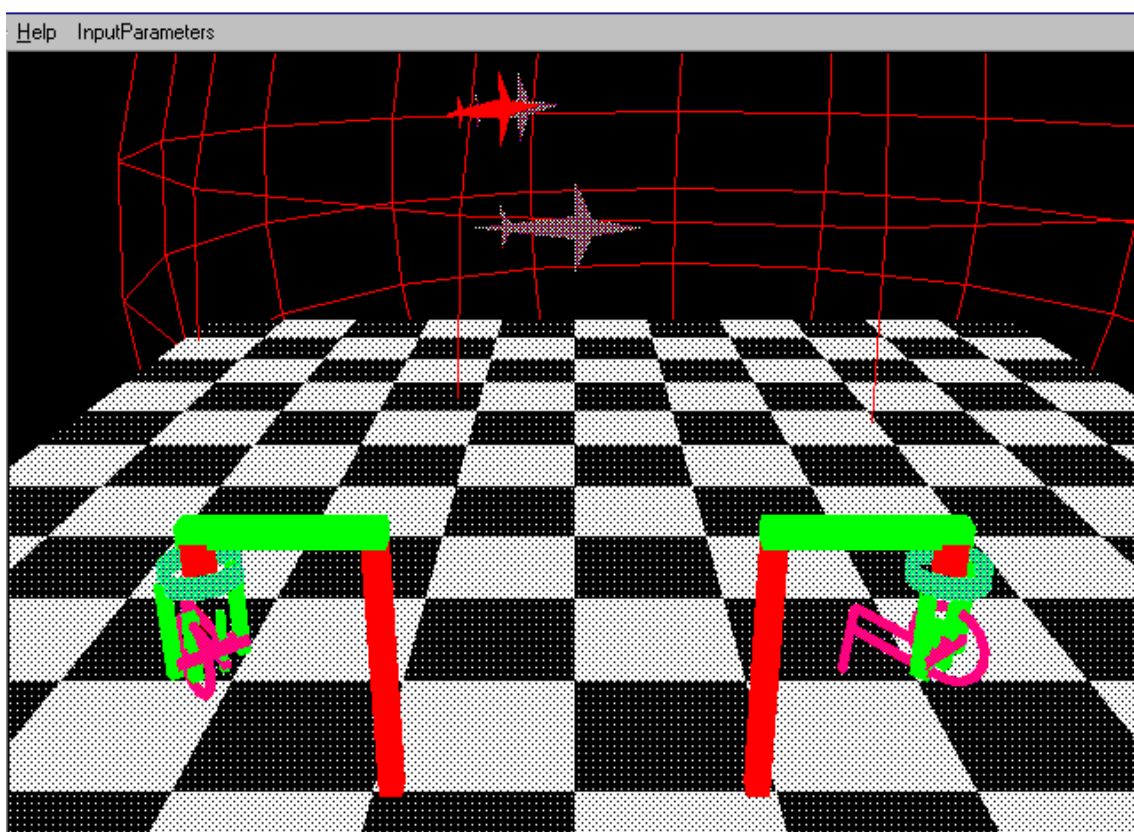


Fig. 1 The example of modeling for the airplane flight control

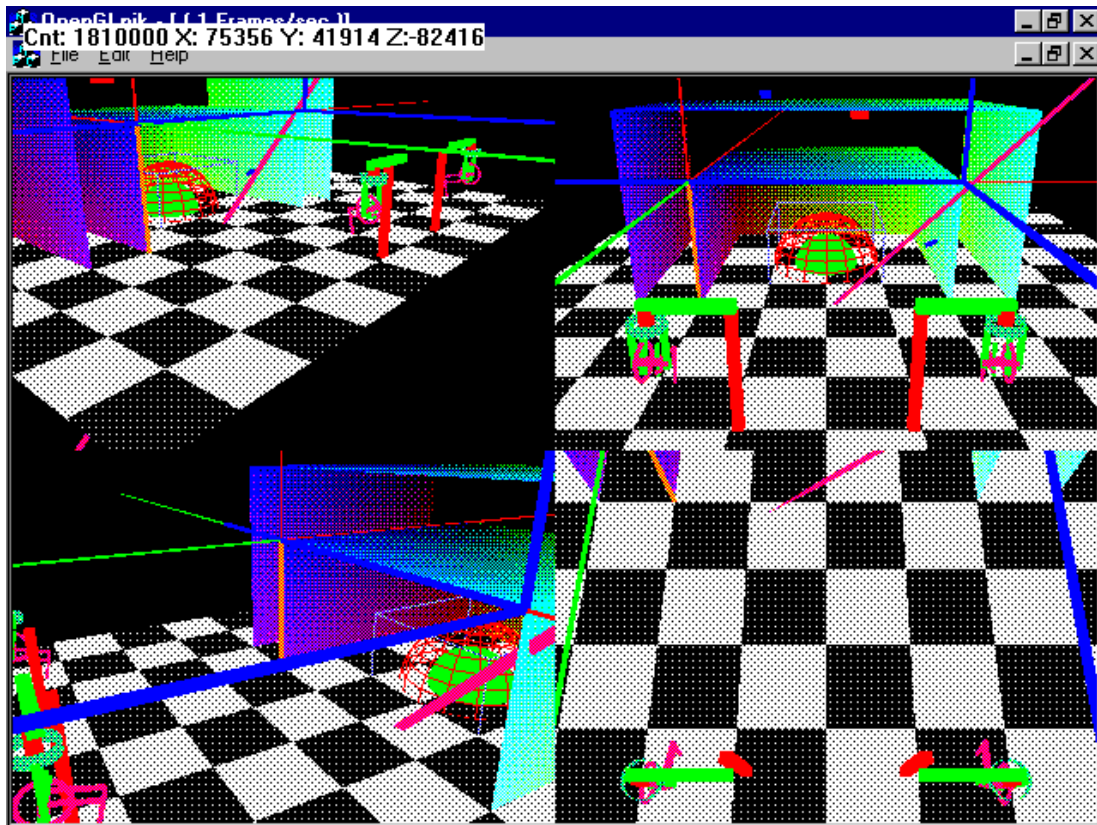


Fig 2 The example of modeling for the virtual 3D object control and virtual parameters modeling in 3D space using master robot and slave robot.

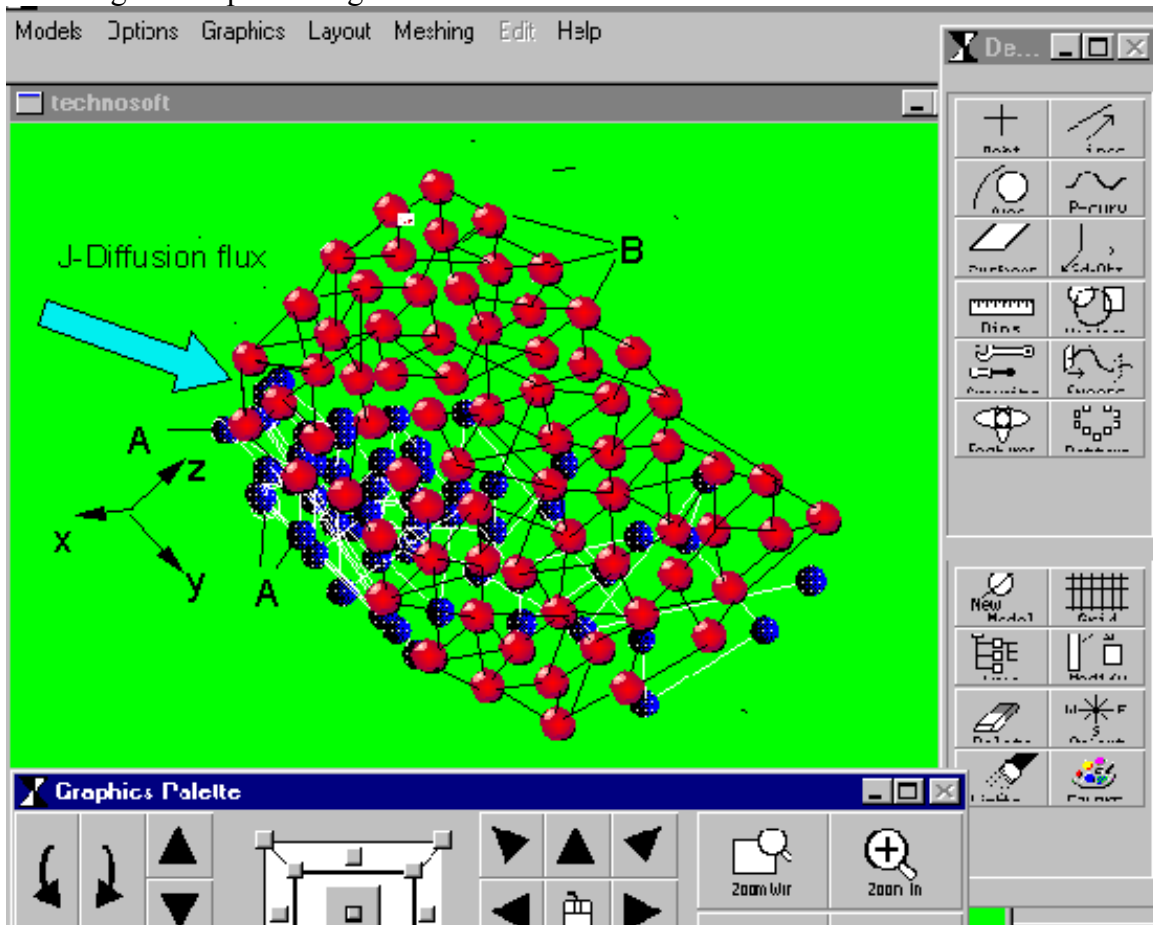


Fig. 3 The spatial-oriented model based on reaction-diffusion equations for modeling diffusion of chemical -A into structure of chemical - B.

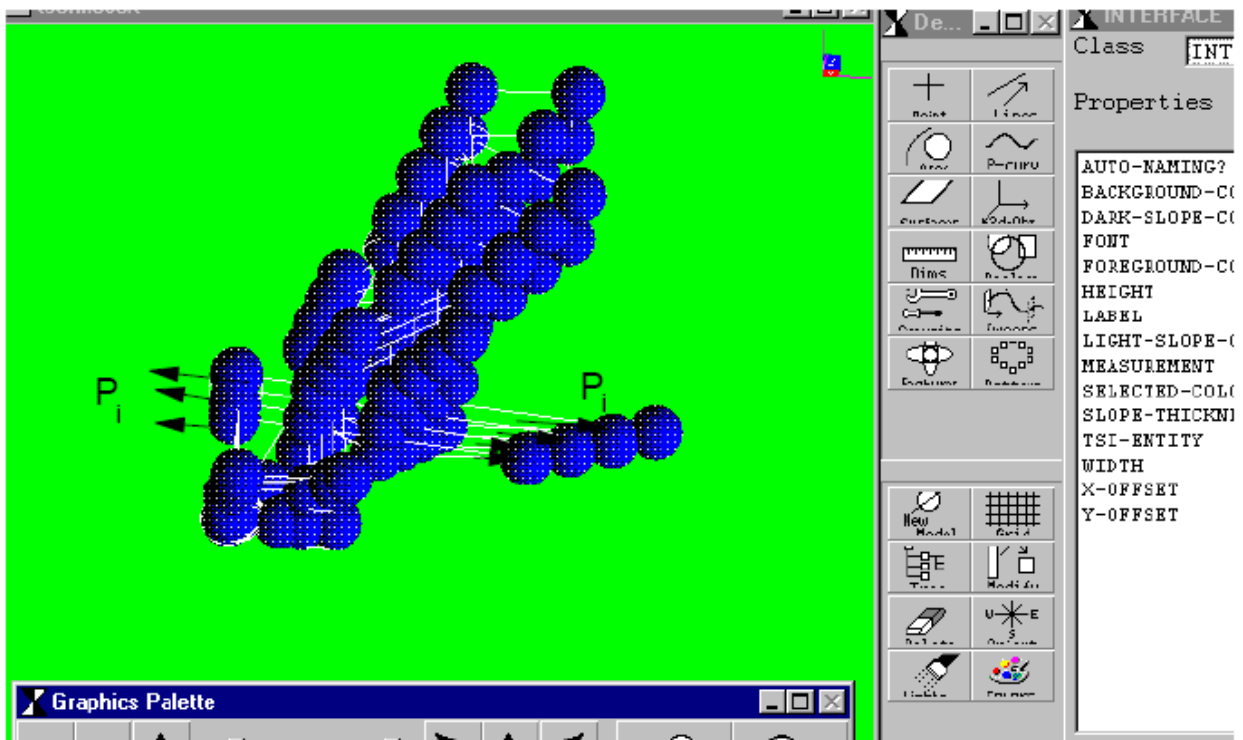


Fig. 4 The model of the deformation process with damage of molecular links under the action of forces P_i based on IPVTS methodology.

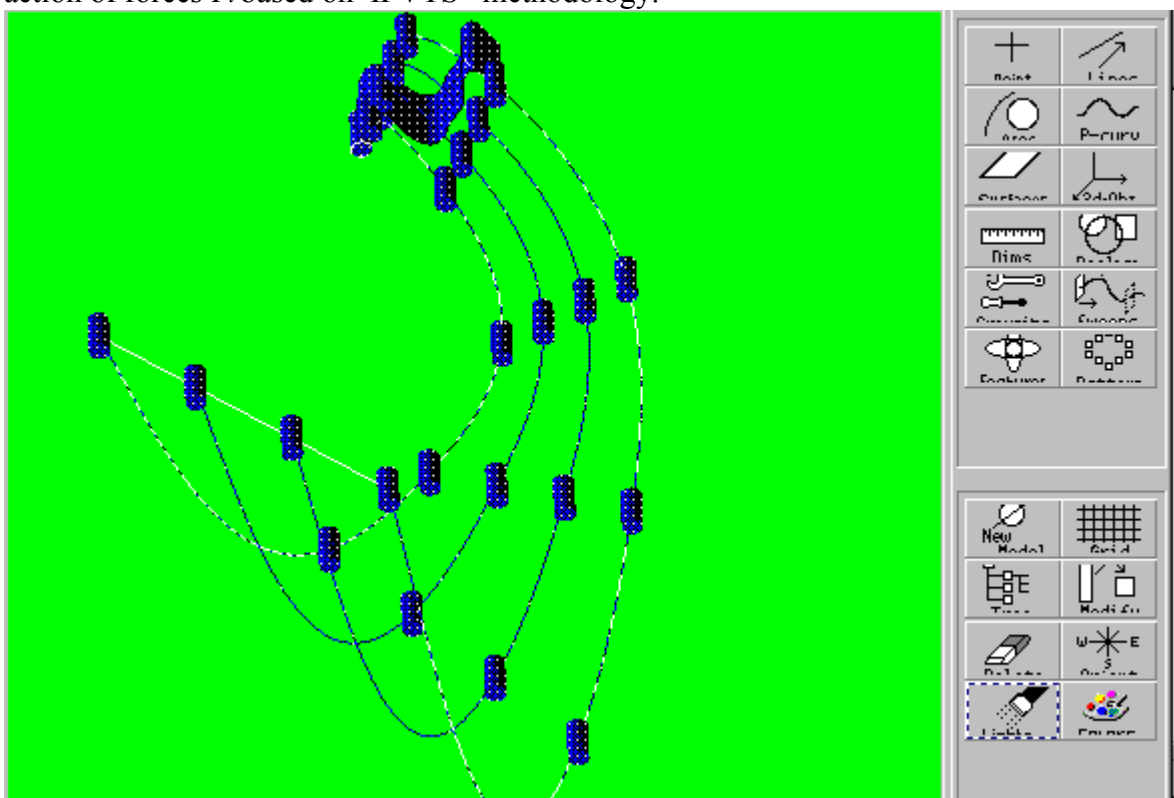


Fig. 5 The trajectory modeling for motion of multi-objects system with nonlinear trajectory using Intelligent Parametric Visual Thinking System

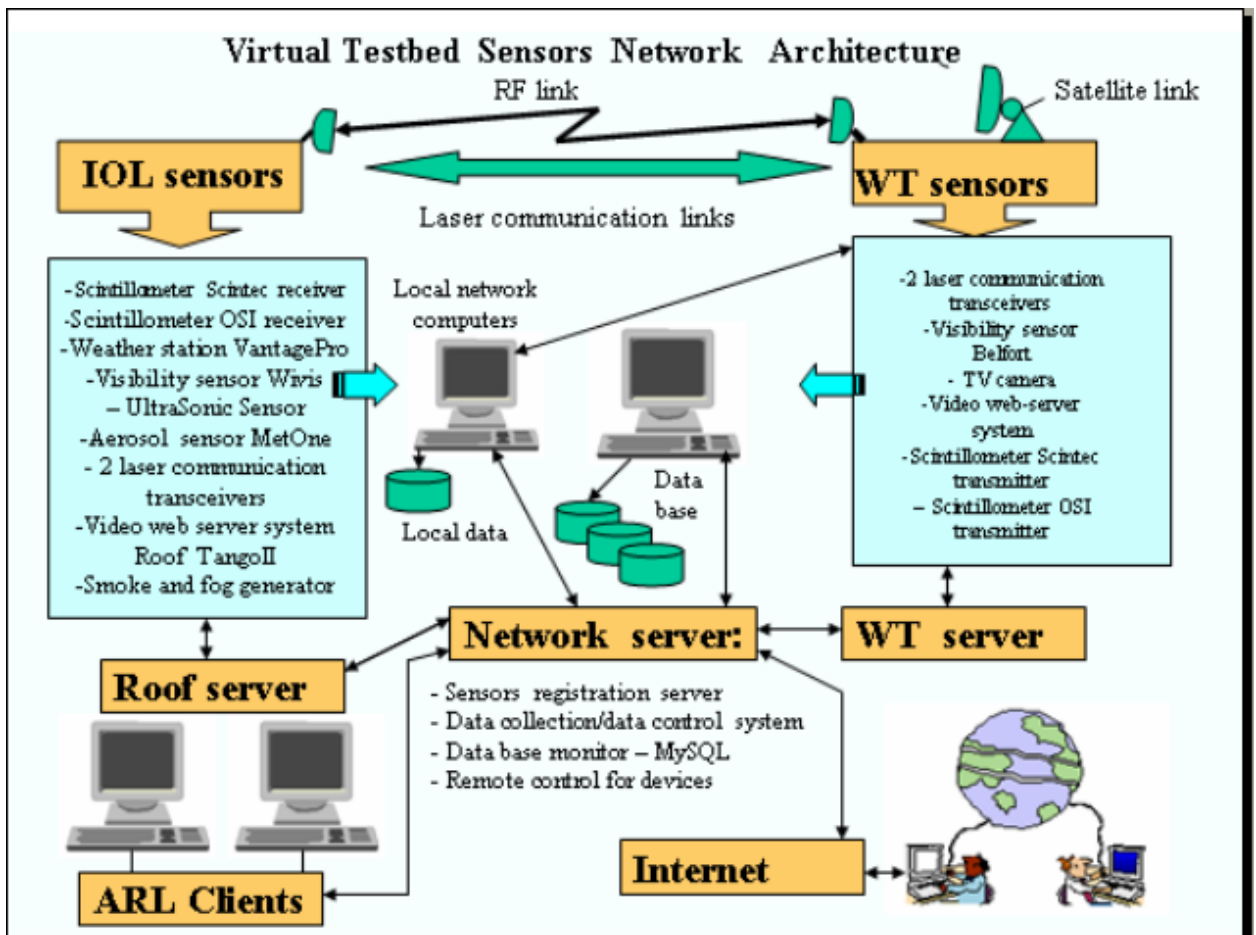


Fig. 6 Virtual Sensors Network Architecture with parallel sensors hardware and smart multi-agent sensors system on remote and locally distributed system

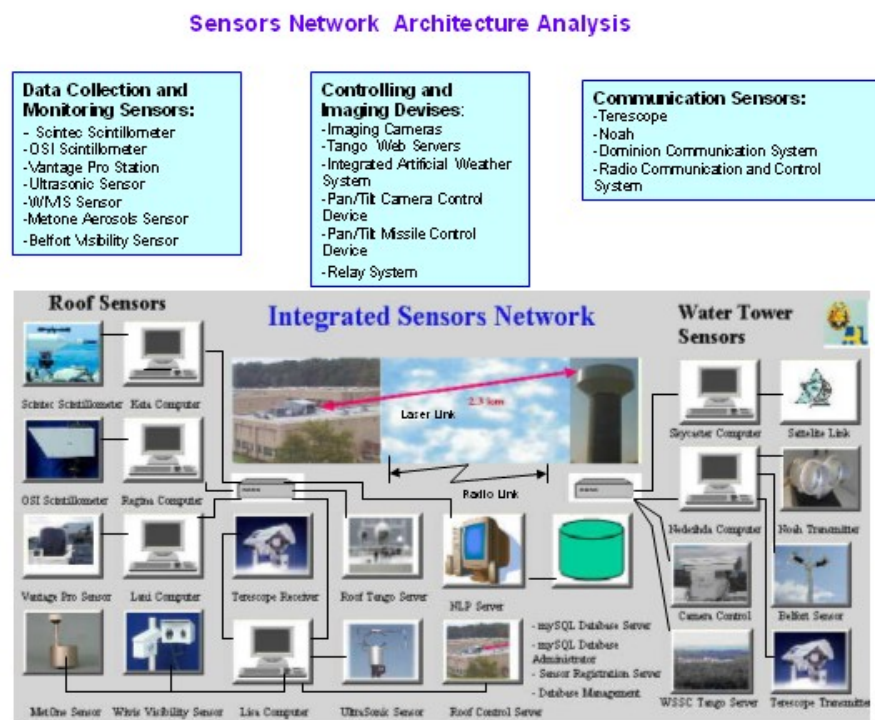


Fig. 7 Virtual Sensors Network Architecture with parallel sensors hardware and smart multi-agent sensors system on remote and locally distributed system.

Status control and monitoring for OSI Scintillometer LOA-004 based on client program

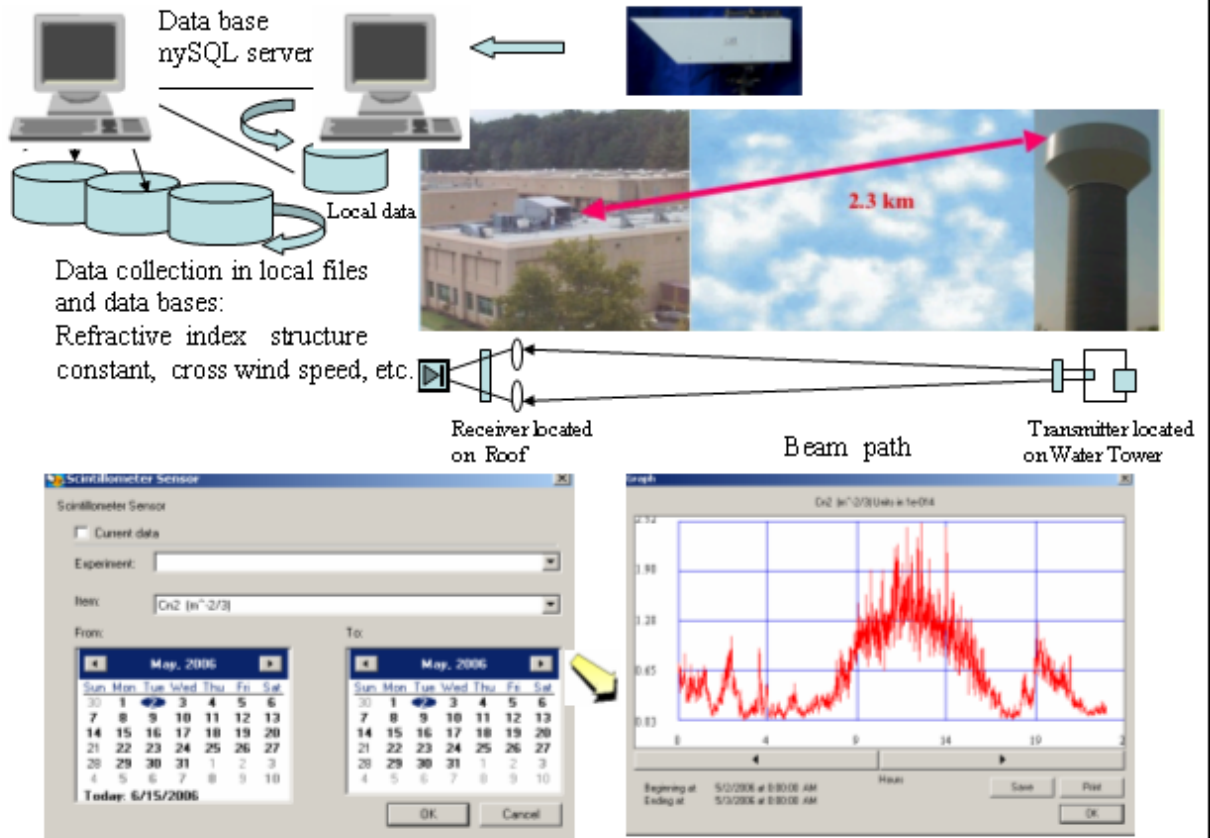


Fig. 8 Status control and monitoring for laser OSI Scintillometer based on smart multi-agent system.

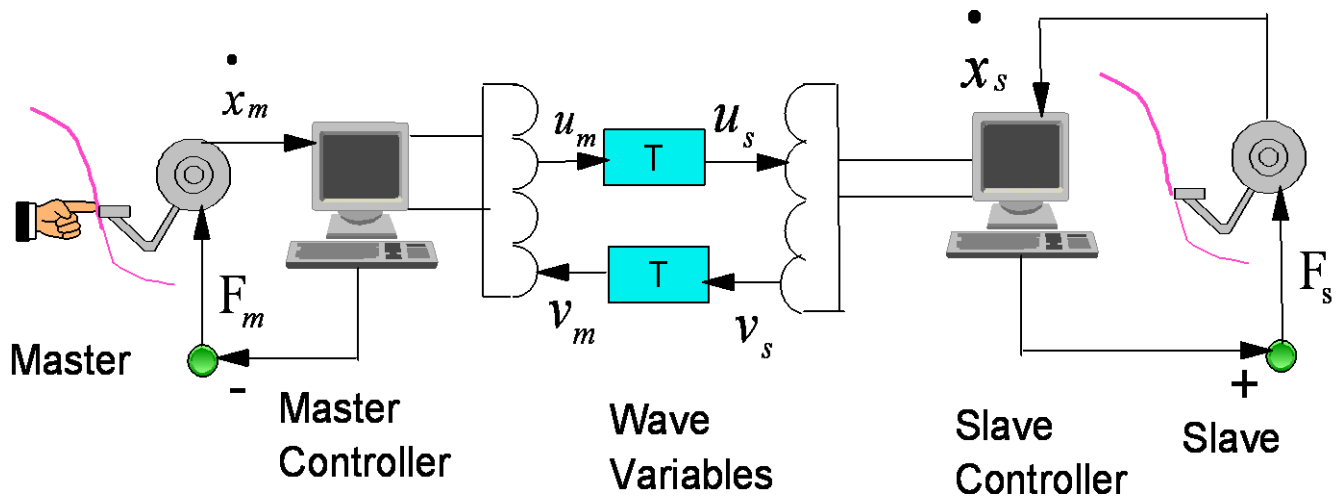


Fig. 9 The remote teleoperation with wave variables based on Niemeyer 's work [Niemeyer 1996].