N90-29051

DESIGN OF A MONITOR AND SIMULATION TERMINAL (MASTER) FOR SPACE STATION TELEROBOTICS AND TELESCIENCE

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Abstract

Based on Space Station and planetary spacecraft communication time delays and bandwidth limitations, it will be necessary to develop an intelligent, general purpose ground monitor terminal capable of sophisticated data display and control of on-orbit facilities and remote spacecraft. The basic elements that make up a Monitor and Simulation Terminal (MASTER) include computer overlay video, data compression, forward simulation, mission resource optimization and high level robotic control. Hardware and software elements of a MASTER are being assembled for testbed use.

Applications of Neural Networks (NNs) to some key functions of a MASTER are also discussed. These functions are overlay graphics adjustment, object correlation and kinematic-dynamic characterization of the manipulator.

1.0 Introduction

Teledyne Brown Engineering (TBE) is completing the independent research and development of a Monitor and Simulation Terminal (MASTER) for use as a Space Station telescience terminal. This effort complements the TBE responsibility for outfitting the Space Station U.S. Laboratory. The terminal is being used within the Robotics Laboratory to investigate techniques to enhance space experiment platform resources such as:

1) Communications bandwidth
2) Crewtime
3) Microgravity

The MASTER is a key element in this effort because it provides the ability to conduct telescience prior to flight and also execute later remote operation of actual equipment and robot systems. The functions that will typically reside in the MASTER are:

1) Video Processing and Overlay
2) Predictive Simulation
3) Intuitive User Interfaces
4) Decision Assistance
5) 3D Modeling and Graphics

The goal of this effort is to provide a telescience platform which can be tailored to specific experimenter resource and operational requirements. The results of this activity will allow a better understanding of user requirements and improve the design of teleoperated experiments.

2.0 Monitor and Simulation Requirements

Predictive Simulation requirements for a MASTER system were first alluded to by Ferrell in 1965 [1]. More recently, Akin [2] and Konkel [3] et al have discussed the importance of predictive visual and force reflective simulation. The simulation and 3D modeling features of the testbed are based on these requirements. Initially our effort has been limited to a predictive visual simulation due to the complexities of predictive force reflection. Our design is also driven by user requirements such as:

1) Maximizing the amount of useful information while minimizing on-screen "clutter"
2) Minimizing head motion to different displays.
3) Providing a mode for uplink control of the manipulator during special situations or contingencies.

3.0 System Design

Basic design requirements for a MASTER are shown in Figure 1. Primary elements include the Simulation Platform and Monitor. The Simulation Platform communicates with the remote site, which includes both robotic and automation elements, as shown in the upper portion of Figure 1.

A simulation-based testbed was chosen for validating algorithms and state of the art control concepts. In this manner, new teleoperations and remote monitoring methods can be easily integrated and adjusted. The task of integrating graphics terminals, video cameras, neurocomputers,and robot manipulators, however, is non-trivial. Although each hardware component is capable of individually meeting its own functional requirements, the combined system must be properly integrated.

The TBE Robotics Laboratory provides a simulated remote work site. This will allow MASTER to ultimately become part of an actual integrated telescience testbed. This includes hardware in-the-loop to simulate time-delayed teleoperations.

A great deal of attention has therefore gone into the design of a "friendly" interface. The operator can utilize a range of input devices. Mouse, keyboard, voice and miniature master manipulators have been used as control inputs. To operate effectively in the presence of time delay, all user inputs can be processed by the predictive simulation. The path of the robot can be modeled by the simulation, in real time, based on the user's inputs. An attempt has been made to minimize the number of displays required. Ideally, a single high-resolution terminal with multiple (possibly voice controlled) overlay windows would suffice. Dual orthogonal camera views using windows were critical during robot control. MASTER also provides an optimum human-machine interface such that an untrained tele-experimenter can become a competent tele-operator within a short time.

The functional design of the MASTER Simulation Platform is shown in the block diagram of Figure 2. In order to have a useful predictive simulation an accurate dynamic and kinematic model of the remote manipulator is provided. In addition, the 3-dimensional perspective of the simulation is automatically aligned with live video from the remote location. The graphics engine, world model, math models (i.e., kinematic/dynamic manipulator models), and neural network models are all used by the predictive simulation.

A high-resolution graphics workstation, with its own geometric pipeline processor, forms the heart of the Simulation Platform. The graphics engine, math models and world models all reside within this computer. Video overlay is accomplished by simulating both the "live" and the predictive views or by the use of live video data and a frame grabber-mixer. The neural network models reside on a PC based neurocomputer workstation. The neurocomputer hosts a scientific vector processing board and associated neural network simulation software.

4.0 Work in Progress

This section briefly discusses our current work in progress. We are emphasizing neural computing applications for use in the MASTER.

4.1 Neurocomputing

Neurocomputing methods and hardware have been applied to the predictive display system. Two such problems are perspective adjustment for accurate simulation overlay and adaptive modeling of the manipulator dynamics. Other areas under consideration are two-dimensional and three-dimensional image tracking and compression, limited resource allocation and force-eye-hand coordination.

We have demonstrated an overlay perspective calibration technique that uses NNs. The problem is to align the perspective of two superposed images so that they appear to be the same image. Figure 3 schematically illustrates the problem we are addressing and the neural controller. Given visual data from an on-orbit (remote) site and a simulated view of that site, control of the simulated perspective until the images overlap is required. The method demonstrated uses a vision computer to digitize each image separately. These images are then processed to provide a measure of translational and scale offsets between the images. These offsets along with the control commands that an operator would use to manually align the images are then given to a NN that uses the generalized delta learning rule of Rummelhart [4] (know as back propagation) to "learn" how to align the images as an operator would. We have been successful in training our system to do perspective line-up to within 5% overlap. A simple logic algorithm has also been developed that will perform this same task. On comparing this algorithm to the neural architectures, it was found that the logic algorithm can be considered a computational subset of the neural network. Figure 4 illustrates the three perspective calibration techniques investigated.

Dynamics modeling is possibly the most difficult problem faced by a predictive simulation. The low gravitational environment in space telerobotics may significantly alter the dynamic response of manipulators. If the manipulator dynamic response is not properly compensated for in the predictive model the simulation may lose its effectiveness. TBE has begun experimenting with NN modeling of the kinematics and dynamics of two-dimensional manipulators. Application of Kohonen's neural model for vector quantization and self-organization [5] has yielded encouraging results. Figure 5 shows how a Kohonen NN can represent the kinematic workspace. The web in Figure 5 is generated by plotting the actual synaptic coupling weights (two per neuron) as two-dimensional points. Lines are then drawn to connect topologically nearest-neighbor neurons. Initially the weights are random; thus the net appears tangled. During learning, random joint angles are used to reposition the arm for each cycle. As learning proceeds the network weights form a representation of the kinematic workspace. Once the neural workspace is created, end effector position vectors along a trajectory can be used to stimulate the trained neurons. This will result in unique time-varying neural activation patterns for every possible trajectory. Figure 6 gives a qualitative view of a typical activity pattern over time. The amount of nodal stimulation will depend on many factors such as trajectory path, speed,acceleration, and neural time constants. We feel that this type of kinematic/dynamic modeling may be useful in the analysis of dynamic changes that can occur under different working environments.

To date, other internal research at TBE has developed a method for constructing practical optical processing components that will eventually provide a MASTER with very high-speed, cost-effective neural network computing power. These include a fixed interconnect optical neural network, a small rugged optical correlation device, and optical associative memory.

5.0 Summary and Conclusions

Efficient man-machine telescience is the goal of this effort. In order to meet such a goal the problem must be viewed from the end user's point of view. We have concluded that a good man-machine interface for practical telescience will require a sophisticated predictive simulation and monitoring platform that is transparent to the user and second nature to operate. This will require the application of new machine intelligence technologies, particularly neural computing.

6.0 References

[1] Ferrell, W. R., "Remote manipulation with transmission delay," IEEE Trans. Human Factors in Electronics, vol. HFE-6, pp. 24-32, Sept. 1965

[2] Akin, Howard and Oliveira, "Human factors in space telepresence," NASAContract NASW3797, SSL#41-83, October 1983

[3] Konkel and Miller, "Telerobotics and Orbital Laboratories: An end-to-end analysis and demonstration,"IAF-87-27, IAF Congress, October 1987

[4] Rumelhart, McClelland and the POP group, Parallel Distributed Processing, MIT press, Cambridge, Mass. (1987)

[5] Kohonen, "Self-organization of topologically correct feature maps," Biological Cybernetics, 43, 59-69 (1982)

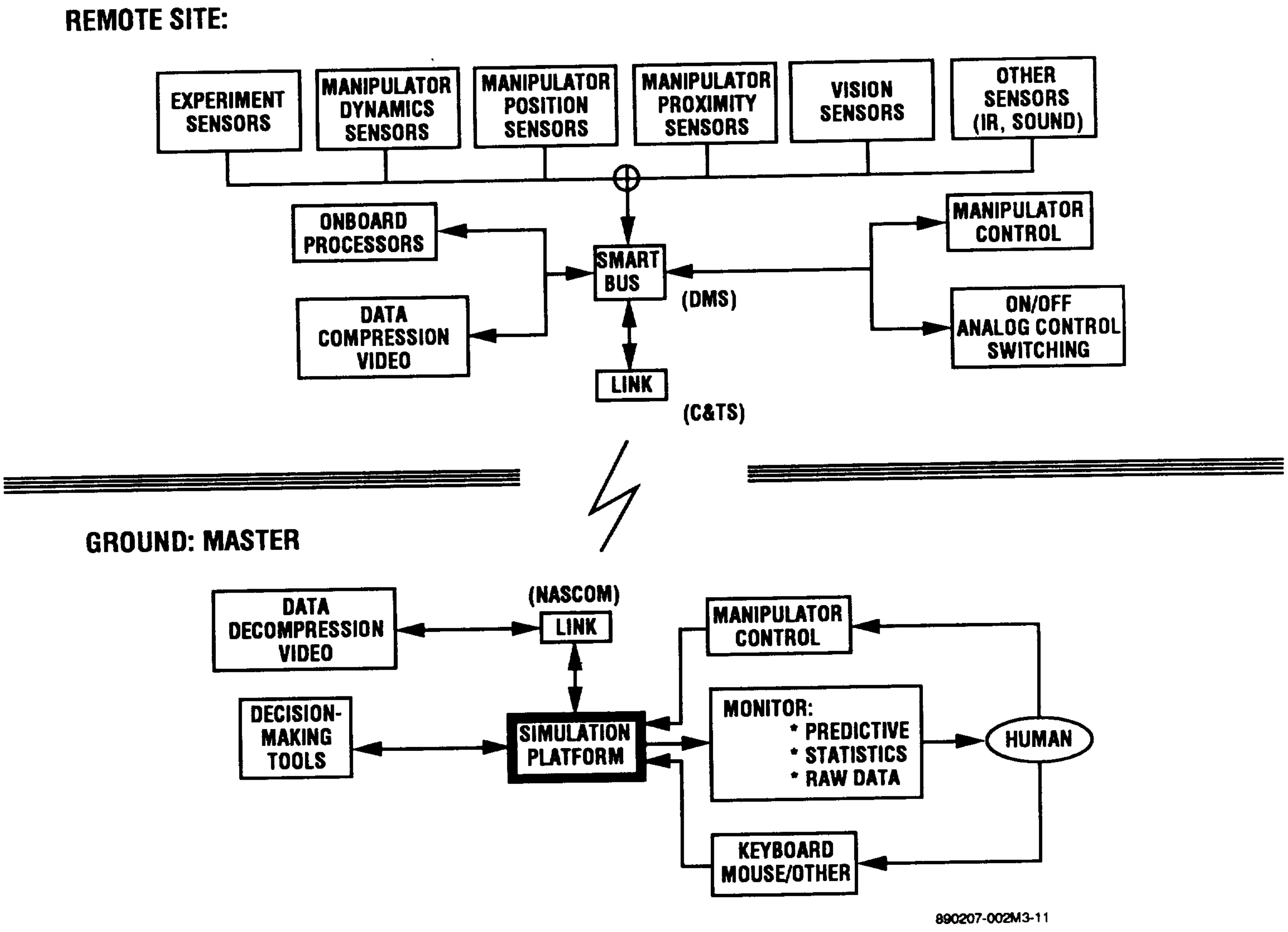
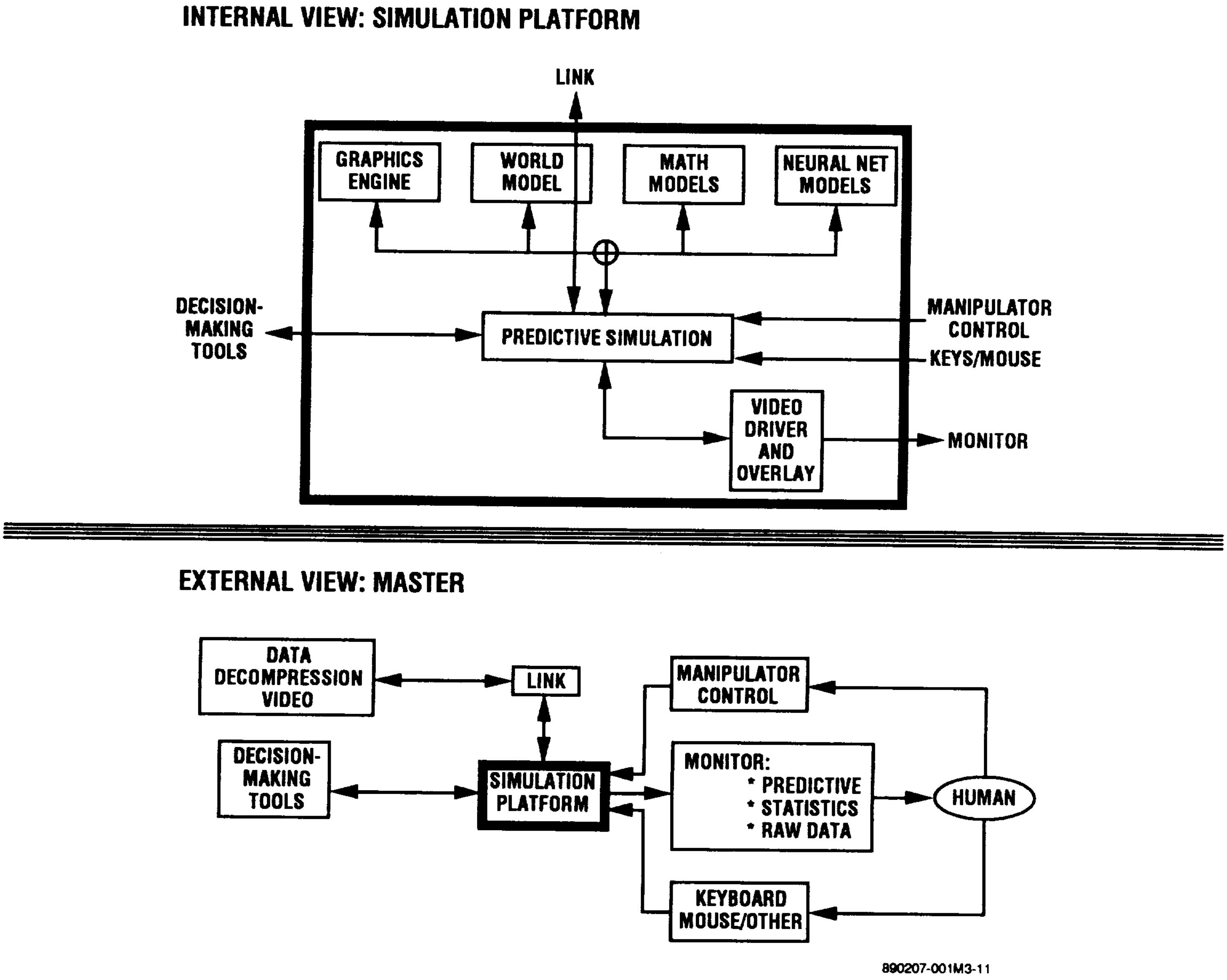


FIGURE 1. BASIC REQUIREMENTS FOR A MASTER SYSTEM AND REMOTE WORK SITE



INTERNAL VIEW: SIMULATION PLATFORM

EXTERNAL VIEW: MASTER

FIGURE 2. SIMULATION PLATFORM BASIC REQUIREMENTS

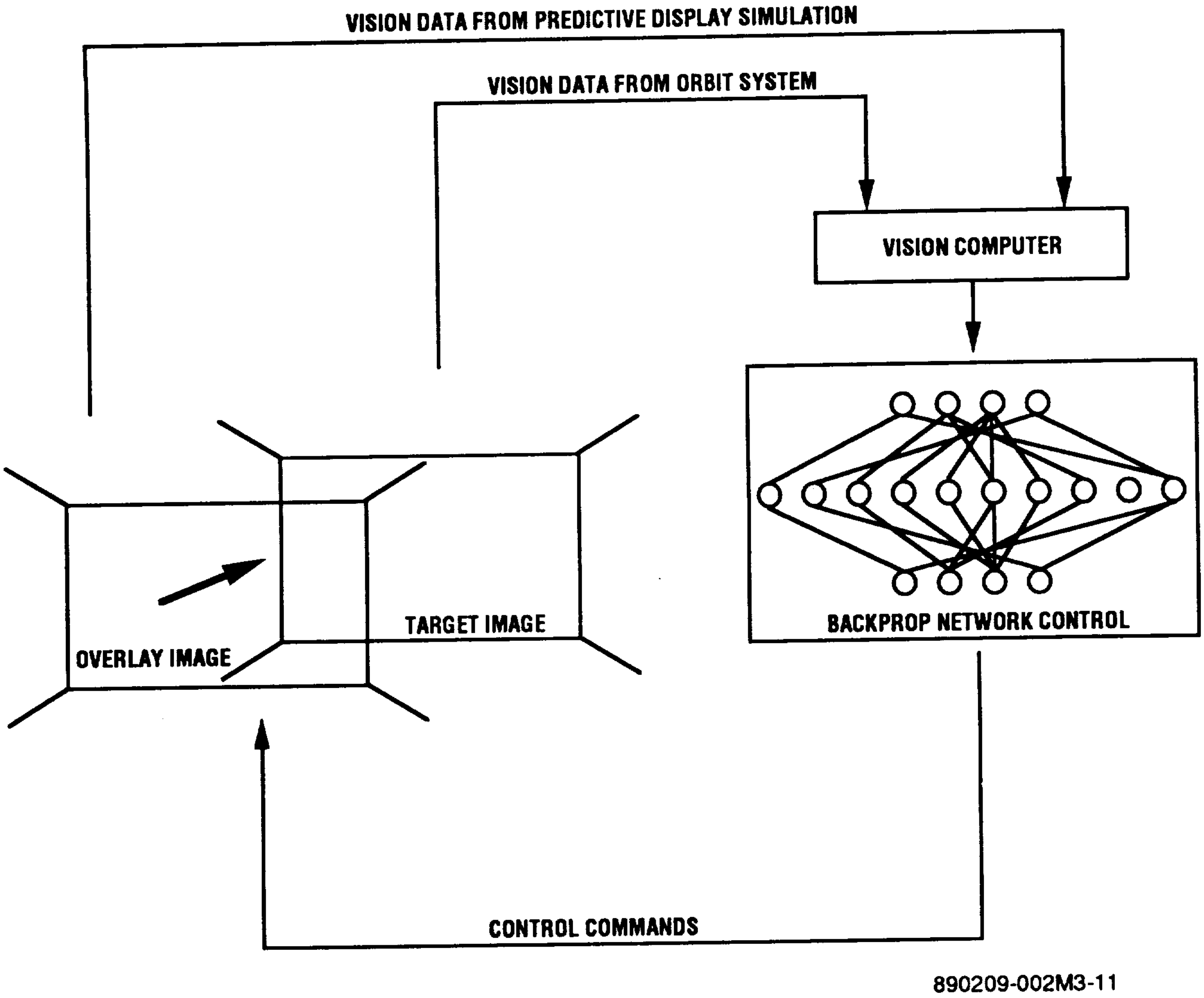


FIGURE 3. INTERNAL RESEARCH DEVELOPMENT OF NEURAL TECHNIQUES FOR PERSPECTIVE ADJUSTMENT

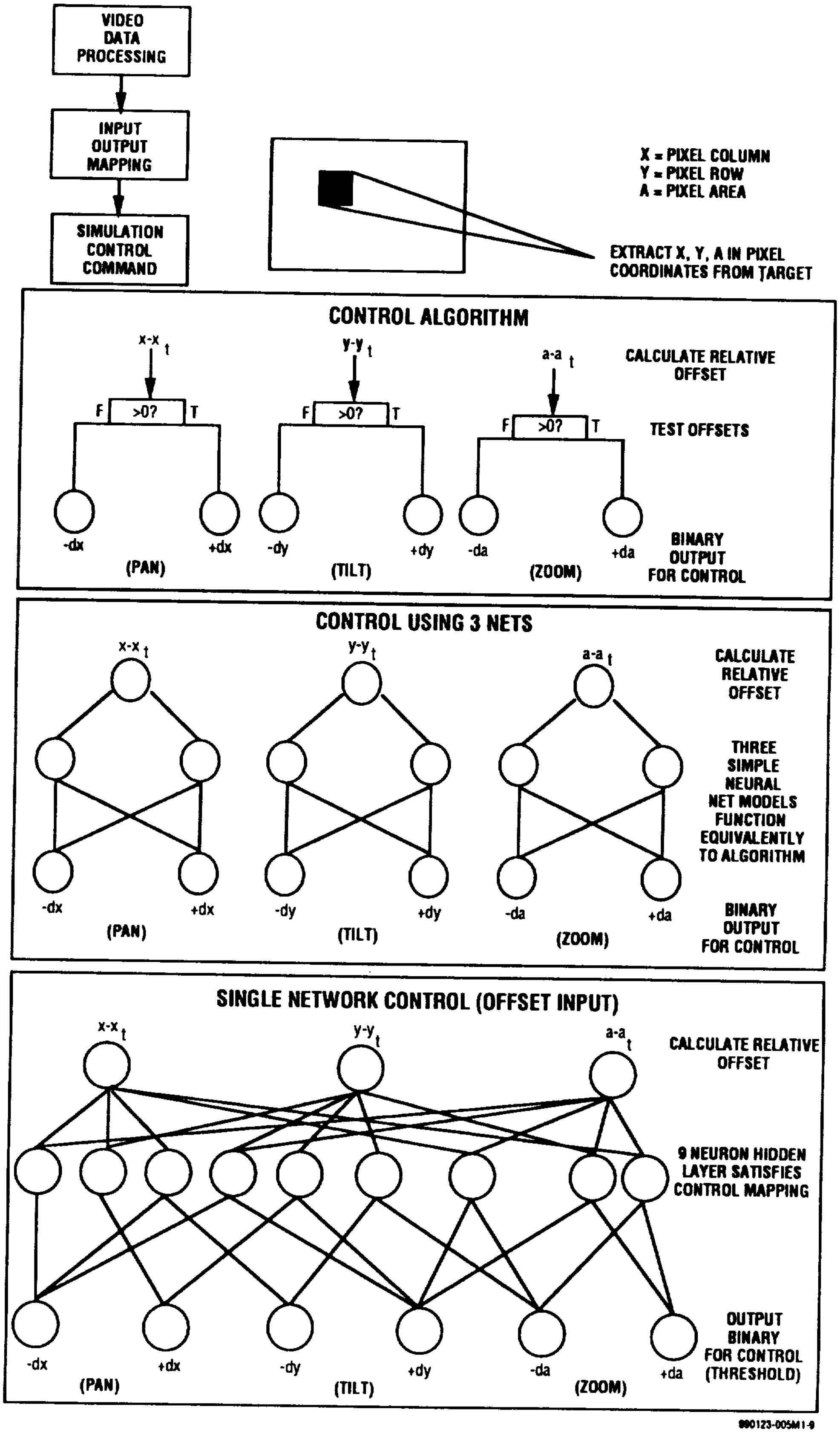


FIGURE 4. THREE PREDICTIVE DISPLAY CALIBRATION CONTROL METHODS WERE DEMONSTRATED

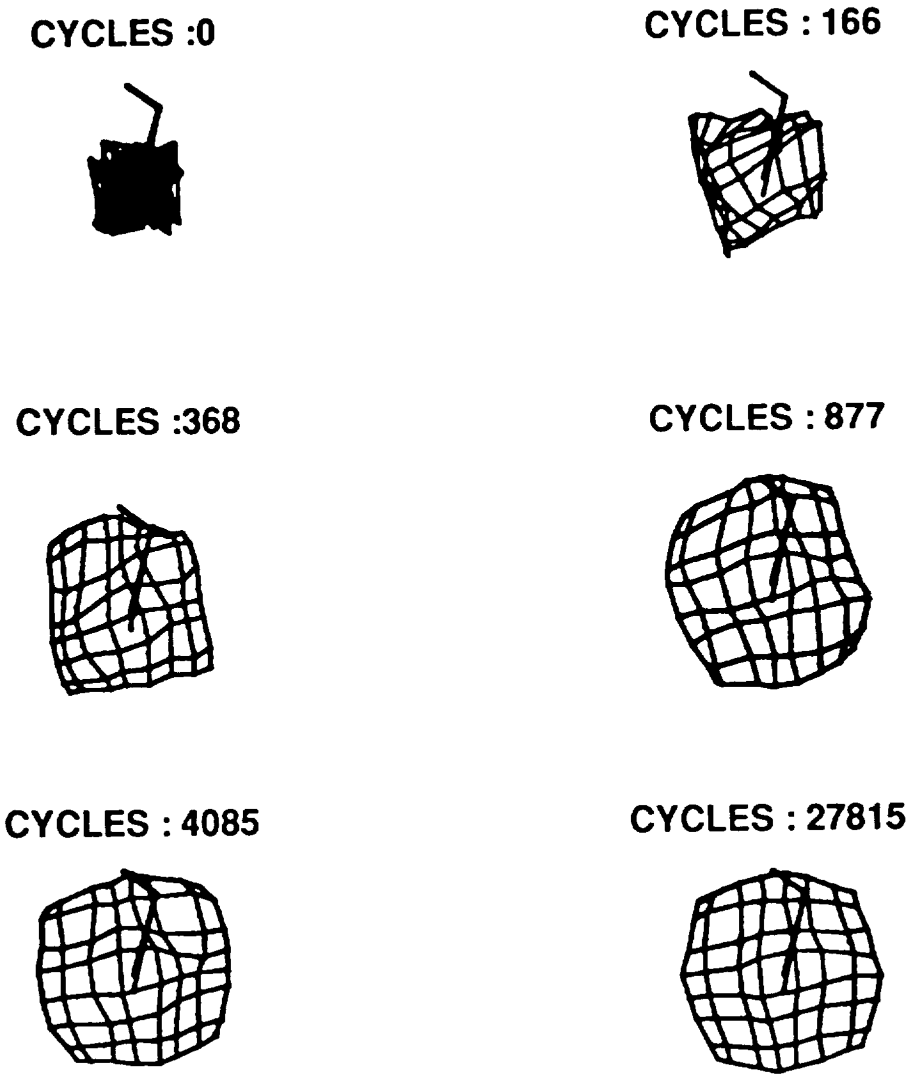


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FIGURE 5. SELF ORGANIZATION FOR MAPPING ARM WORKSPACE/ PROBLEM DOMAIN

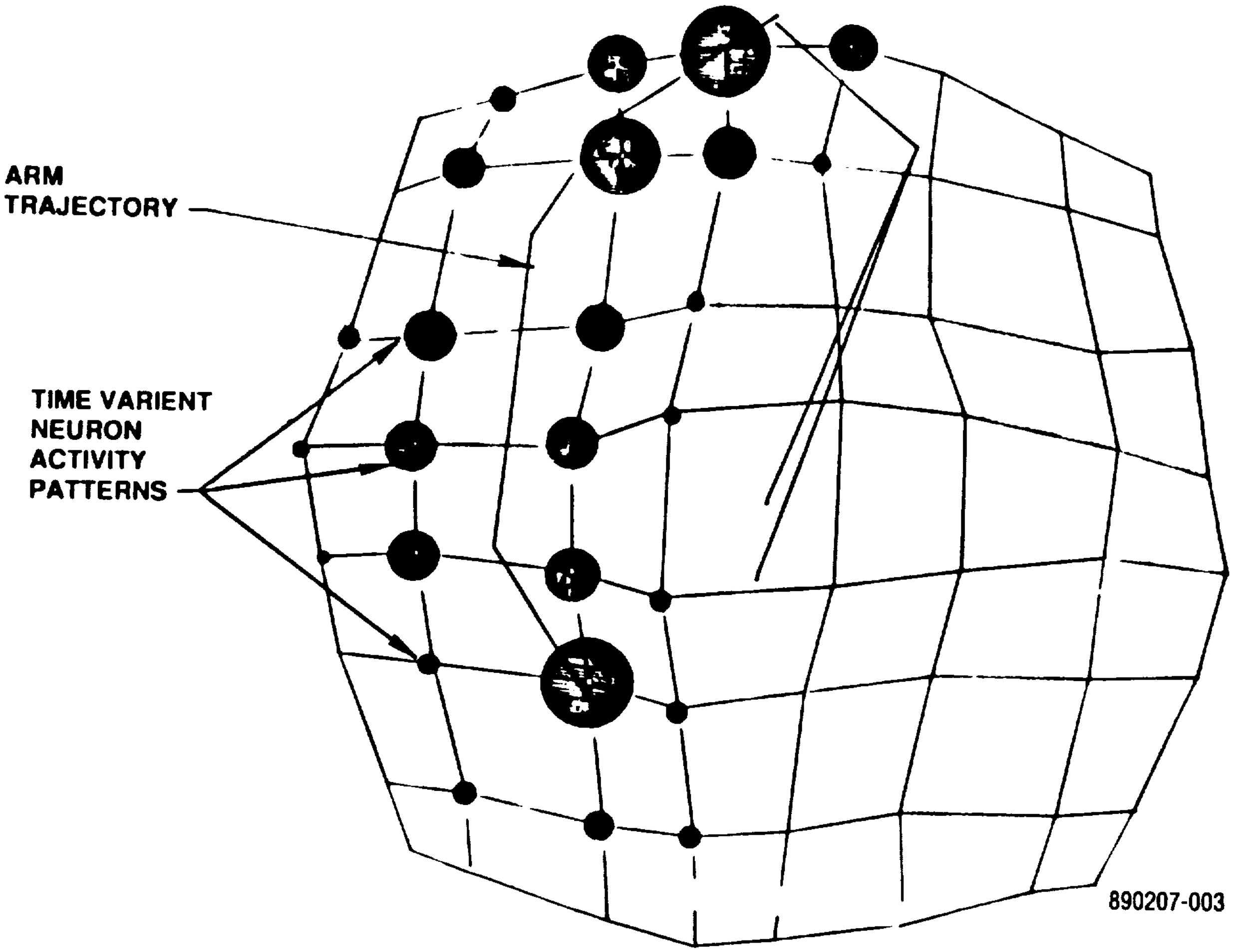

FIGURE 6. ACTIVATION PATTERNS IN SELF-ORGANIZED MAPPINGS: DYNAMICS MODELING