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THE ORBITAL MANEUVERING VEHICLE TRAINING FACILITY VISUAL SYSTEM CONCEPT

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ABSTRACT

The purpose of the Orbital Maneuvering Vehicle (OMV) Training Facility (OTF) is to provide effective training for OMV pilots. A critical part of the training environment is the Visual System, which will simulate the video scenes produced by the OMV Closed-Circuit Television (CCTV) system. The simulation will include camera models, dynamic target models, moving appendages, and scene degradation due to the compression/decompression of video signal. Video system malfunctions will also be provided to ensure that the pilot is ready to meet all challenges the real-world might provide. This paper describes one possible visual system configuration for the training facility that will meet existing requirements. This paper reflects work performed for NASA by CAE-Link Corporation.

INTRODUCTION

The OTF visual system must provide the CCTV capabilities at a cost-effective price. The scene content update rate is only 5 times per second with a low-resolution requirement. This enables the use of a high-end super-graphics workstation as the medium for the CCTV simulation. Combining the CCTV simulation with the full-feature OTF simulation maximizes pilot training. To further enhance training capabilities, stand-alone and integrated modes will challenge the pilot with limited and full-mission scenarios.

The stand-alone mode provides the pilot with a partial-task, one-on-one training environment that guides the pilot's progress in a systematic manner. Integrated mode allows the linking of the OTF with several simulators at NASA, Johnson Space Center (JSC). Integrated mode will challenge the pilot to apply the lessons learned from the stand-alone sessions with new and more difficult mission objectives. Both modes enable the pilot to handle any situation that could possibly occur in an actual mission. The functional design diagram for the OTF Visual System (figure 1) shows the relationship of the host computer with the Image Generation system and also depicts the two configurations available for the integration with respect to the Visual System.

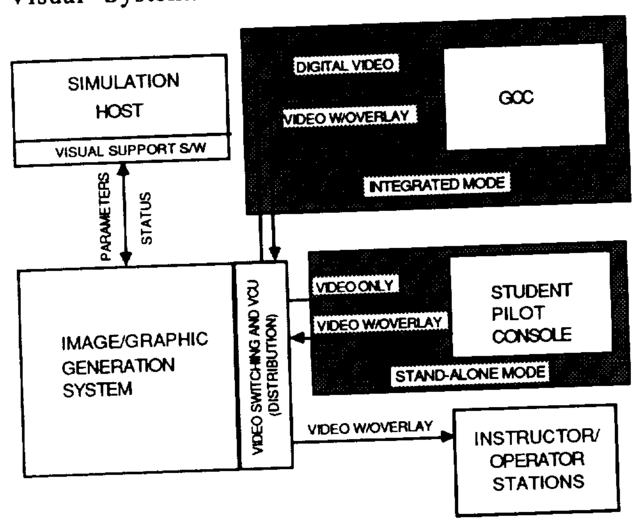

FIGURE 1 OTF Visual System Functional Design Diagram

The OMV is a remotely-piloted spacecraft. Currently defined mission scenarios include rendezvous and docking with satellites, the Orbiter, and the Space Station. To provide training for these missions, a simulation environment is being developed to train the

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pilot to interact with the OMV. Before detailing the OTF Visual System, an explanation of the real-world OMV is in order. Familiarity with the actual system is essential to understand the training requirements and how our functional simulation of these systems will provide effective training for OMV pilots. A basic functional diagram of the OMV CCTV system is presented in Figure 2. It provides the data flow from the time an image is captured by the CCTV camera, to when the image appears on the pilot's display.

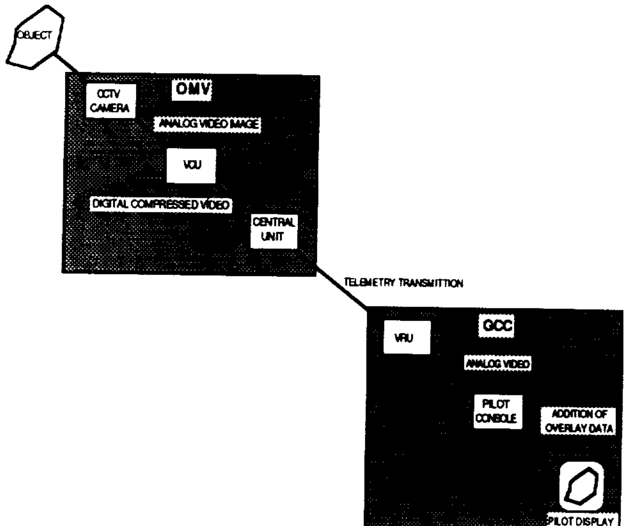

FIGURE 2 OMV CCTV Functional Diagram

OMV VIDEO SYSTEM

The OMV has two independent and redundant camera systems: docking and pan/tilt/zoom. Lighting equipment is associated with each camera system. Four additional cameras can be attached to OMV payloads, making a maximum of eight cameras allowed. Camera images are sent to the pilot at the Ground Control Console (GCC) in the JSC Mission Control Center (MCC) via the Tracking and Data Relay Satellite System (TDRSS). The camera images are compressed and placed into the OMV telemetry stream. The bandwidth available for the video telemetry is only 972 kbps, or 5 video frames per second. The 972 kbps telemetry data rate can be allocated to two cameras at 486 kbps each or can be dedicated to a single camera. At MCC, the GCC decompresses the telemetry and performs error checking. The video image is then combined with an overlay of flight-critical data and displayed to the pilot.

Camera System

The pan/tilt/zoom camera is a redundant system with a 6:1 zoom ratio and is typically used by the pilot for initial acquisition of the target vehicle and for the initial stages of OMV docking. The docking camera is also a redundant system and is mounted on the OMV docking axis. This permits the pilot a boresight view of the target docking mechanism alignment with the OMV grapple mechanism. Two redundant docking lights are included with each camera system for a total of four lights.

Video Compression Unit

The Video Compression Unit (VCU) compresses the video images. The VCU utilizes a frame-grabbing technique to acquire 5 frames of RS-170 video data per second in normal operational modes. Compression and Huffman and Reed-Solomon encoding are performed on each frame of data. In the event that a single docking light is the only available light source, the pilot can select an extended imaging mode that extends the usable camera range to 200 feet. The extended imaging mode increases the VCU video sample rate and combines multiple frames of data into a single enhanced image. This is analogous to increasing the exposure time of a photograph in a camera, allowing the film to receive multiple images that combine for a single photograph. The VCU also provides the capability to send memory dumps from the OMV Command and Data Management systems to the GCC.

Video Reconstruction Unit

The Video Reconstruction Unit (VRU) decompresses the digitized video images. Huffman and Reed-Solomon decoding is also performed. The VRU has an additional unit attached called the Bit Error Rate Monitor (BEM), which provides verification of pixel count, line count, and correct subframe sequence in the video frame. The BEM replaces sections of corrupted data with data from the previous frame. The pilot can increase the number of reference pixels, which lowers the resolution of the image being transferred and reduces the amount of corrupted data. Not only will the granularity of the picture increase but also the validity of the image.

Ground Control Console

All commanding of the OMV is done via the GCC. The pilot has a redundant station with a keyboard, two cathode-ray tubes (CRTs), and rotational and translational hand controllers. Preprogrammed commands are entered via the operator's workstation. The GCC workstation receives OMV telemetry and displays it to the pilot. The pilot console receives the RS-170 output from the VRU and adds the overlays that contain flight-critical data. This output is then displayed on the CRTs. The video image has a resolution of 510 by 244 pixels for a single camera image or 255 by 244 for two cameras.

OTF VISUAL SYSTEM CONCEPT

The OTF Visual System must provide two separate modes of operation: stand-alone and integrated. In each of these modes, the camera system of the OMV must be simulated. From these CCTV models and from target control data, the Image Generation System will generate the representative scene to be displayed for the OMV pilot.

Basic requirements for the Visual System include simulation of the CCTV system, transport of visual data to MCC, decoding of the data, and addition of flight-critical parameters to the display for the pilot. The OTF Visual System will use a combination of hardware and software on two different computer systems. One computer will provide modeling information while the other will transform that information into a graphic representation. An image generation computer will produce the CCTV camera scenes for the pilot with a host computer controlling the simulation models of the vehicle camera systems. The host computer also provides all commanding of the Image Generation System. All database modeling will be performed on the Image Generation System.

Training Configurations

Providing both stand-alone and integrated simulation capabilities is required to supply various levels of training. During initial pilot training, the stand-alone mode allows instructors to remain in close proximity to the student pilot. Instruction on basic system operation and scenarios is given. Partial task/mission training is also possible. The OTF Visual System will provide all nominal system capabilities. In this mode, no effects caused by telemetry degradation or compression/decompression of the video signal will be simulated.

The integrated mode connects the OTF with the Shuttle Mission Simulator (SMS), Network Simulation System (NSS), and MCC. This mode provides full mission scenario training and refines the pilot's proficiency and skills. The OMV pilot is placed in situations as close as possible to an actual flight, from prelaunch to Orbiter retrieval. All interactions with MCC and Shuttle personnel occur as they would in an actual flight.

Both modes must provide image generation, CCTV, and target control. The differences lie in the distribution of the video image to the pilot, the GCC, or the student pilot console.

Video Distribution

The OTF Visual System produces the raw video image as directed by the host simulation. This video is in RS-170 format to remain compatible with the pilot console/student pilot console hardware.

Integrated Mode: A VCU is used on the OMV to convert and compress the video image into digital telemetry. A non-flight-rated version of the VCU is used in the integrated mode to perform Reed-Solomon encoding and compression of the Image Generation System video. The VCU outputs this data to the Data Acquisition System (DAS), which places the video into the OMV downlink telemetry.

The real-world pilot console is used in integrated training. The pilot's visual hardware consists of a VRU, a frame grabber and graphics generator, and two graphics CRTs. The VRU accepts digital video from the telemetry network and converts the digital compressed signal to RS-170 format. The frame grabber on the GCC acquires the image and adds the overlay of flight-critical data. This composite image is then displayed for the pilot.

By using the real-world VCU and VRU, additional capabilities are available for training. This includes command and data handling memory dumps, BEM effects, and telemetry degradation effects.

Stand-alone Mode: In the stand-alone mode the output of the Image Generation System is directly routed to the student pilot console; only the addition of switching capabilities and signal amplifiers is necessary. No telemetry degradation and no compression/decompression effects are simulated in the stand-alone mode. This approach reduces the complexity and cost of the OTF simulator.

OMV Host Computer

The OMV host computer has several resident math models. These models include simulation of the OMV environment and onboard systems. The OTF Visual System encompasses the following areas:

- CCTV
- Visual Real-Time Support
- Visual Mode and Control
- Visual Special Effects

Closed-Circuit Television

The CCTV models dynamically simulate the CCTV camera system on the OMV. All telemetry data is passed from the camera systems to the central unit. The central unit then places the data into the telemetry stream that is sent to MCC. The central unit also passes this information to the redundancy management unit for wellness checks and appropriate self-reconfiguration in event of correctable malfunctions. The CCTV camera system consists of the pan/tilt/zoom camera, docking camera, docking lights, and the VCU.

Pan/Tilt/Zoom Camera Model Functions

1) Thermal effects are modeled to provide telemetry data to the central unit.

2) The electrical system is modeled to provide status information to the central unit. Electrical power consumption data is provided to the OMV onboard systems electrical system model. This model provides all power-available data for the CCTV model.

3) The camera gimbal control respond to command data from the GCC. These commands generate data that is sent to the image generator. The mechanical and electrical dynamics are simulated. The net effect is the movement of the simulated camera.

4) Gamma, focus, and iris control from the GCC are simulated as near to the real-world as is possible with the image generation hardware.

Docking Camera Model Functions

1) Thermal effects are modeled to provide telemetry data to the central unit.

2) The electrical system is modeled to provide status information to the central unit. Electrical power consumption data is provided to the OMV onboard systems electrical system model. This model provides all power-available data for the CCTV model.

3) Gamma, focus, and iris control from the GCC are simulated as near to the real-world as is possible with the image generation hardware.

Docking Lights

1) The luminosity control commands for the docking lights will be sent to the Image Generation System.

2) Thermal effects are modeled to provide heat transfer information to the camera thermal models.

3) The electrical system is modeled to provide status information to the central unit. Electrical power consumption data is provided to the OMV onboard systems electrical system model. This model provides all power-available data for the CCTV model.

Telemetry outputs deemed necessary for training but not previously defined will be provided.

Processing of malfunctions will be provided at the level of detail specified in the Level B requirements.

The host computer (Concurrent 3280) contains mathematical models for the OMV and its environment. These models include the CCTV system and the control of free-flying targets. The host computer models propagate all state vectors for the OMV and the free-flying targets. When the CCTV system is in view of a free-flying object, commands are given to the Image Generation System to place the target at the given state vectors. All camera parameters (field of view, focus, iris, gamma correction, and lighting control) are sent with the state vector data to the Image Generation System.

Camera focus is required for OMV training. For the systems investigated, no focus or blur commands were available in an off-the-shelf product. A focus algorithm will be derived using pixel pairing or filter algorithms.

Visual Real-Time Support Software

The Visual Real-Time Support software provides commands for the image generator. OMV target and Earth/Moon/Sun information and data are processed. This process includes the conversion of all Concurrent floating point numbers to industry standard Institute of Electrical and Electronics Engineers (IEEE) floating point format.

a) Earth/Moon/Sun

   1) State vector IEEE conversions must be performed for the Image Generation System

   2) The luminosity of the Sun must be set to provide correct representation of the day/night terminator and shading of objects.

b) OMV Visual Model and Target Control

   1) State vector IEEE conversions must be performed for the Image Generation System

   2) Appendages are commandable with representative visual cues reflecting the actions.

   3) Navigation lights are represented as polygons and do not add any shading or luminosity effects.

Visual Mode and Control

The visual mode and control software provides the functions necessary to maintain the simulation modes (run, freeze, data store, and return to data store). This software commands the following subsystems:

a) Image Generation System - The image generation mode and control also includes the model selection and image generation initialization.

b) Video Distribution System - The video distribution mode and control configures the distribution hardware with predefined parameters for the mode selected. It also allows system reconfiguration as needed when the simulation is in freeze mode. Freeze mode allows the simulator to halt and suspend all integrations, as if time has stopped inside the simulator.

c) Video Compression Unit - The VCU mode and control software initializes and modes the VCU hardware (only in integrated simulation mode). A representative model of the VCU is used in the stand-alone mode.

Visual Special Effects

All special effects (such as focus and radio frequency interference (RFI) noise) hardware will be controlled by the visual special effects software. Only the use of step attenuators to degrade the OMV telemetry stream when sent to the GCC in MCC is planned.

Image Generation

The image generation software is required to produce a new scene 5 times per second. With this low scene content update rate, it is possible to use a high-end super-graphics workstation. We estimate that 35,000 four sided polygons per second are required for a 5 hertz update rate. This estimate was produced by using existing SMS and space model databases. The scene content must include the Sun/Earth/Moon and the possibility of four-free flying targets.

Image Generation Software

The image generation software provides the following capabilities:

- Network connectivity
- Initialization mode processing
- Message processing
- Sequencing
- Screen-application processing

The workstation also provides all capabilities for database model generation.

CONCLUSIONS

The OTF provides an effective training environment for the OMV pilots. Training flexibility is achieved using the stand-alone and integrated modes. In stand-alone mode the pilot is introduced to the basic handling capabilities of the OMV. The pilot can then proceed to basic procedures and scenarios and be challenged by instructor-inserted malfunctions. In the integrated mode, the pilot is integrated into the NASA team and learns to work with all other MCC ground controllers and Shuttle personnel. Enhanced capabilities are added to the VCU and VRU within the command and data handling simulation. The capability to degrade the video image proportionally to the amount of telemetry degradation is inherent in the system and is supported by the visual cues the pilot receives as a result of his commands. These reactions in combination with the capabilities described above provide a realistic and effective training environment for the OTF.

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