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Unmanned Vehicle Guidance Using Video Camera/Vehicle Model

(MSFC Center Director's Discretionary Fund Final Report, Project No. 97–23)

T. Sutherland
Marshall Space Flight Center, Marshall Space Flight Center, Alabama

December 1999

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LIST OF ACRONYMS

CCD	charged coupled device
CDDF	Center Director's Discretionary Fund
DSP	digital signal processor
EEPROM	electronically erasable programmable read only memory
EXVM	experimental vector magnetograph
FFT	fast fourier transform
FPGA	field programmable gate arrays
NT	new technology
RAM	random access memory
STS	Space Transportation System
UART	universal asynchronous receiver/transmitter
VGS	video guidance sensor
VME	versa module eurocard

TECHNICAL MEMORANDUM

UNMANNED VEHICLE GUIDANCE USING VIDEO CAMERA/VEHICLE MODEL
(Center Director's Discretionary Fund Final Report, Project No. 97–23)

1. INTRODUCTION

The purpose of this Center Director's Discretionary Fund (CDDF) project was to improve the state of the art of vehicle navigation by two methods: (1) Improve current video guidance sensor (VGS) capabilities by redesigning the video sensor assembly; and (2) create an algorithm development system that could be used to produce a camera/vehicle modeling method for vehicle tracking. Figure 1 depicts the docking scenario for the basic VGS system.

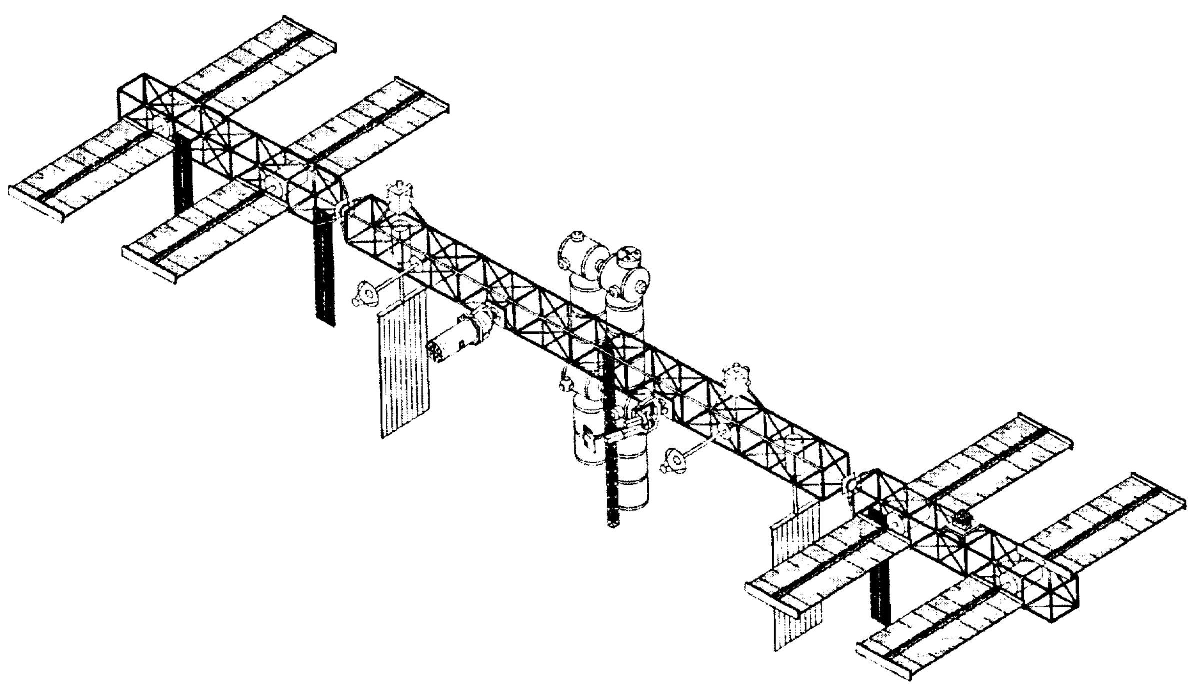

Figure 1. Docking scenario for the basic VGS system.

2. DESCRIPTION

Figure 2 depicts the VGS system which flew on STS–87 and STS–95. This system uses a single camera as the imaging device. Two successive images are captured with each image scene. For example, the target vehicle with retroreflector is illuminated by two lasers of different frequencies. The two images will be the same except that the retroreflectors have a filter over them that absorbs one of the laser frequencies. The difference image, created by subtracting the two images, only reveals the targets and no other objects. Figures 3 and 4 demonstrate this difference image process. By knowing the dimensions of targets and their relative positions, the relative position of the camera can be computed. This current configuration can only support a navigation update rate of 5 Hz due to the heavy burden of image subtraction.

Limitations and restrictions of the current VGS system are as follows:

- It requires target vehicle to be fitted with a group of retroreflectors.
- The target vehicle viewing angle is very limited.
- Other types of guidance must be used to maneuver the target into a good viewing angle.
- The update rate is limited by hardware and software tasks.

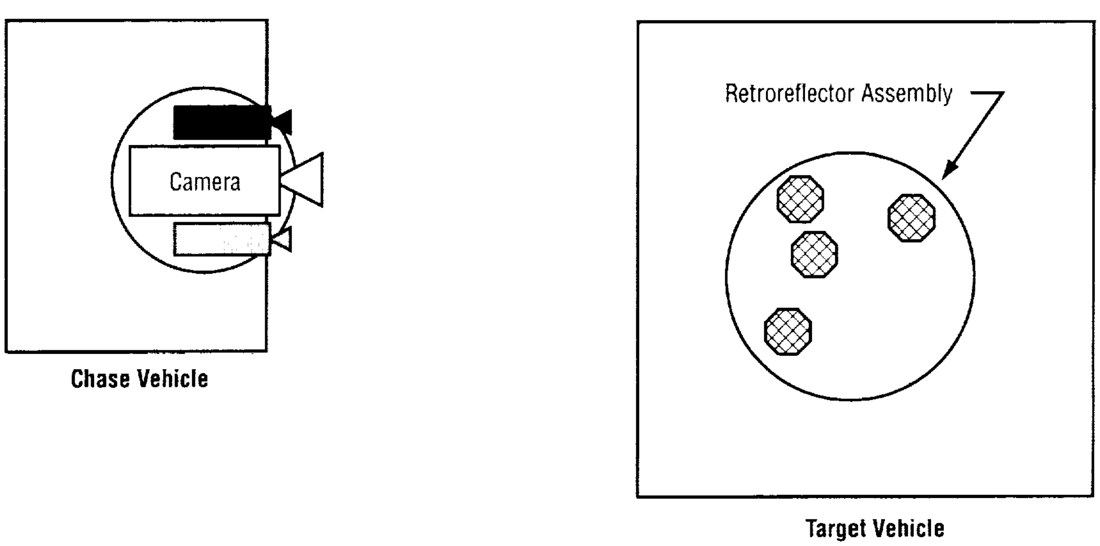

Figure 2. Current VGS system configuration.

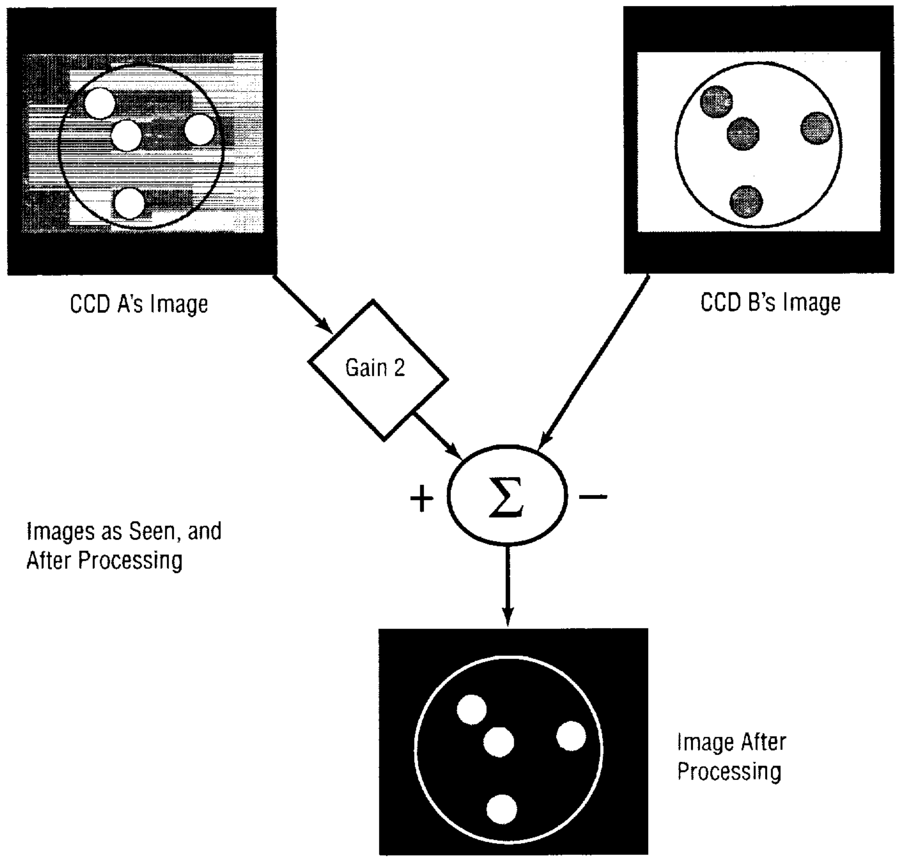

Figure 3. Current VGS image resolution—images as seen and after processing.

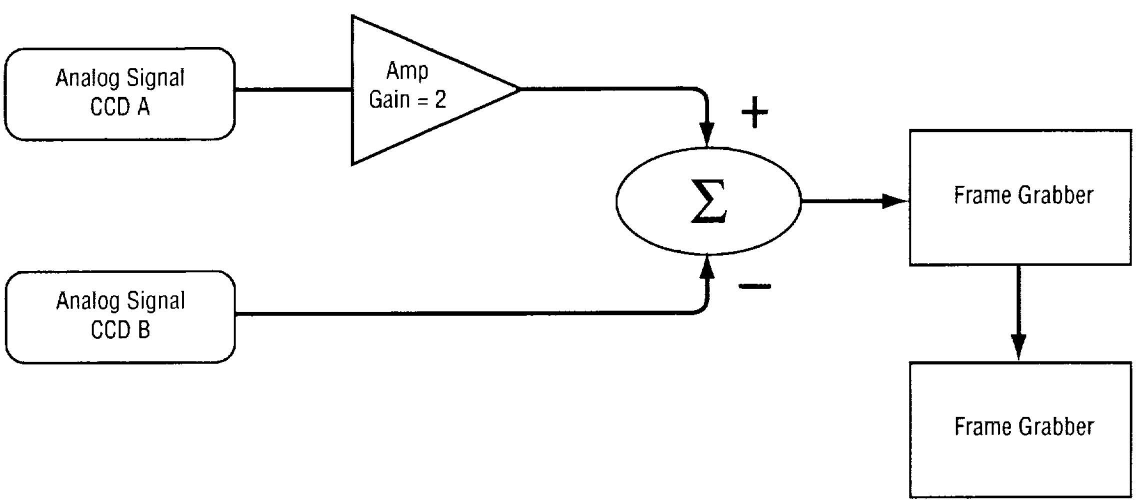

Figure 4. VGS analog section.

3. APPROACH

Three methods were used to improve the current VGS:

- Implementation of the image subtraction algorithm was accomplished using hardware to speed up the navigation update rate. A typical example would be a subtractor using a memory lookup table and field programmable gate arrays (FPGA's).
- Development of both the hardware to implement image acquisition and the software/algorithm development system.
- Optimization of the hardware/software development platform to allow for development and testing to determine the best algorithm that would allow tracking and coordinate acquisition using a single camera/nontarget based system.

4. DEVELOPMENT

The first 2 yr have been dedicated to designing electronic hardware, selecting optical components, and literature searches. A TMS320C40 digital signal processor (DSP) based processing card was designed and built. The DSP board can accept an optional daughter card for specific design applications. This board has already been adapted to work on another CDDF project, the Experimental Vector Magnetograph (EXVM) Experiment, as the heart of the video processor system, thus proving the usefulness of the DSP/daughter card concept. The EXVM video processing system uses two DSP boards and two special purpose video interface daughter cards. Figure 5 depicts the TMS320C40 system.

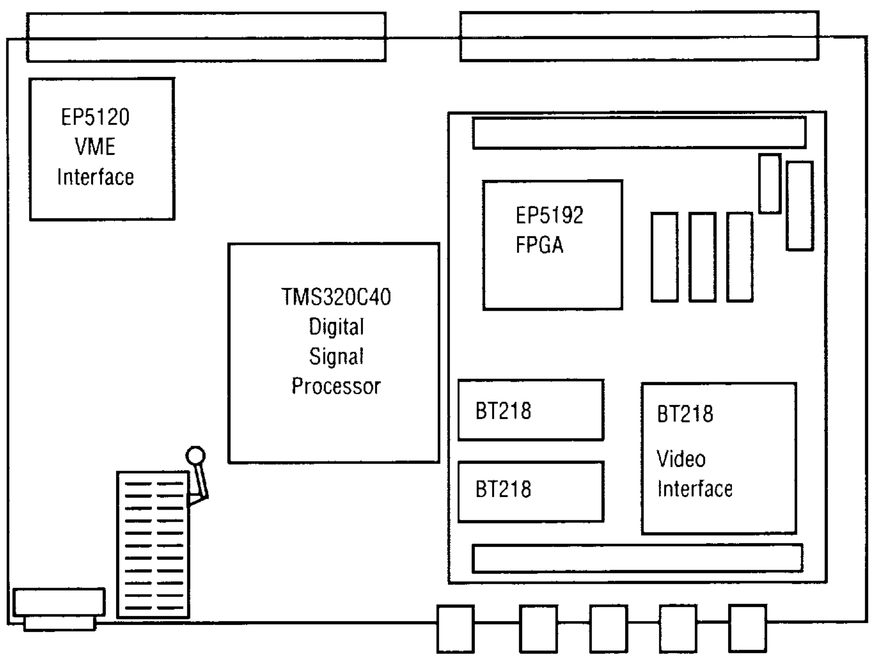

Figure 5. VGS C40 main and video mezzanine boards.

Two additional video interface daughter cards have been built for the CDDF project pertaining to this paper. One card takes the Wavelet transform of the image in hardware using a dedicated Wavelet transform chip. The second daughter card has been developed with the capability to digitize one or two camera inputs. This card can be configured to read and store camera inputs or preprocess images before passing data to the DSP for further processing. Preprocessing is accomplished in an FPGA. Types of preprocessing include edge detection, background and image subtraction, and possibly fast Fourier transform (FFT).

Methodologies for vehicle tracking have been studied and have been incorporated into the design of the model-based vehicle tracking system. One approach to vehicle attitude determination is using an aspect ratio calculation. The aspect ratio of image data is calculated and compared to a database of precalculated aspect ratio calculations. A "best fit" is determined by comparison of peaks in the aspect data. This method needs further investigation and may be combined with other methodologies such as "feature space trajectories."[1] Figures 6 and 7 depict the advanced VGS camera configuration and system overview.

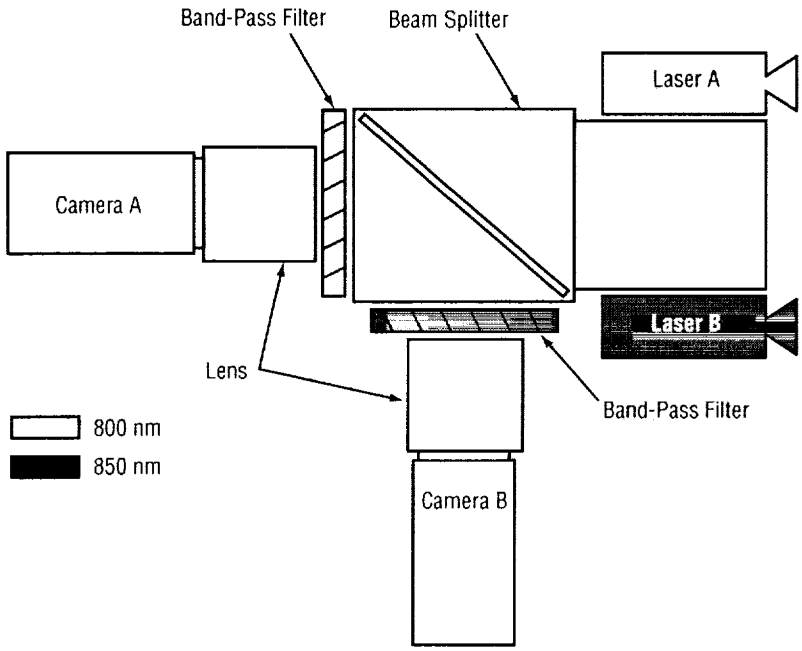

Figure 6. Advanced VGS new camera configuration.

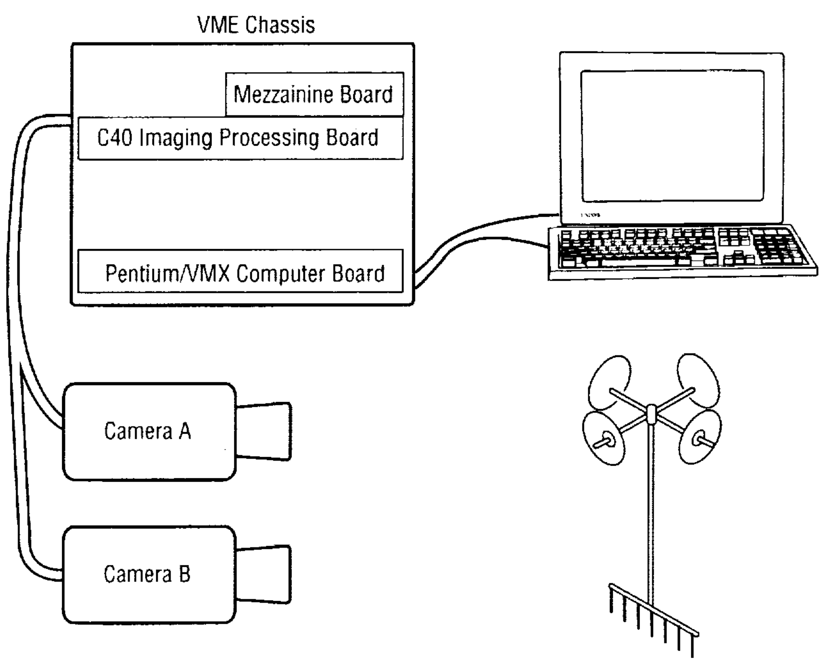

Figure 7. Advanced VGS system overview.

5. ADVANCED VIDEO GRAPHICS ADAPTER SYSTEM SPECIFICATIONS

5.1 Hardware

- TMS320C40 Texas Instrument® DSP board
- 50 MHz (40-ns instruction time)
- 128k words of local static RAM
- 512 kbytes of boot electronically erasable programmable read only memory (EEPROM) (reprogrammable on board)
  - Universal Asynchronous receiver/transmitter for serial communications
  - Full 6U, 32-bit versa module eurocad (VME) interface
  - Interface for mezzanine board
  - Video interface mezzanine board
  - 128 kbytes of static RAM
  - Dual camera inputs, accepts RS–170 or National Television Standard's Committiee video input
  - Subtraction of images done by EEPROM lookup table via FPGA
  - Video passes through an FPGA for additional processing capabilities.

- Pentium-based VME bus computer
  - Running Windows NT[2]
  - Full VME master controller/interface.

5.2 Software

- MATLAB[3] v5.3 used for algorithm development and VME interfacing
  - Algorithm development
  - C–development platform
  - Graphical user interface for development platform.

- C++ Language on Windows NT® running under MATLAB
  - C running on the TMS320C40 DSP
  - Assembly language running on the TMS320C40 DSP.

6. CONCLUSION

The design of the entire VGS development system was a learning experience. The development scope of the system consisted of two areas: (1) Hardware construction and testing, and (2) research into providing the best resources for this type of work. The system that was produced has already been used on another EXVM project and will probably provide other projects with the groundwork for getting started. The development system can provide a platform for many areas of research, not limited to navigation. The ability to develop algorithms and to test them in real hardware is a needed resource and can be only one step away from having a space-qualified platform.

7. FUTURE WORK

The system for development of a model-based tracking system has been established. The combination of the dual-camera concept and model-based tracking system needs to be further developed so that a robust and adaptable vision guidance system will be available for current and future guidance applications. Although further algorithm development and improvement is lacking, hardware to implement and test the model-based algorithm is now available.

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1. Casasent, D.; and Sipe, M.: "Feature Space Trajectory Representation and Processing for Active Vision," *SPIE Vol. 2904–8,* 1996.

2. *Windows NT V4.0*, Microsoft Corp., 1996.

3. *MATLAB,* The Mathworks, Inc., 1996.

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13. ABSTRACT *(Maximum 200 words)*

A video guidance sensor (VGS) system has flown on both STS–87 and STS–95 to validate a single camera/target concept for vehicle navigation. The main part of the image algorithm was the subtraction of two consecutive images using software. For a nominal size image of 256×256 pixels this subtraction can take a large portion of the time between successive frames in standard rate video, leaving very little time for other computations. The purpose of this project was to integrate the software subtraction into hardware to speed up the subtraction process and allow for more complex algorithms to be performed, both in hardware and software.

14. SUBJECT TERMS
image subtraction, algorithm, vehicle navigation, STS–87, STS–95, VGS

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