LUNAR MICRO ROVER CAMERA SYSTEM DEVELOPMENT

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ABSTRACT

The objective of my internship at NASA Ames Research Center Robotics Academy is to develop a Camera System flexible enough to allow the user to switch seamlessly between Navigation mode and Recording mode. One task was to determine how many packets the link could drop before the image became too distorted for the human operator to drive. Another task was to explore image compression techniques for low bandwidth connections but still be able to drive the rover. Basics in Electronics and C Programming were taught in order to achieve this objective. A commercially available IP webcam mounted on a rover testbed was used to determine teleoperation capabilities with two Linux-based computers connected via Ethernet mimicking a lossy environment.

INTRODUCTION

The NASA Ames Robotics Academy comprises of FIRST (For Inspiration and Recognition of Science and Technology), VEX, and Botball students and alumni as well as members interested in the field of Robotics. The Ames Robotics Academy was started by NASA Civil Servant, Mark Leon, an avid FIRST emcee at various Robotics Competitions. The Robotics Academy is one of several ways NASA is cultivating STEM (Science, Technology, Engineering, and Math) leaders, focusing more on college and high school level students.

The Lunar Micro Rover is the ongoing project at NASA Ames Robotics Academy. The goal of the project is to create inexpensive Lunar Micro Rovers capable of enduring the Lunar environment. The mission involves deploying two Micro Rovers to the moon by 2012, each capable of carrying out specific objectives such as Micro-Payloads, Lunar Exploration, Extended Deployment, and Tele-Operation. Members of the Robotics Academy are assigned to their specific subgroups: Structural Integrity System, Power Control System, Communications System, Command and Data Handling System, Rover Avionics System, Camera Payload System, Thermal Control System, Radiation Mitigation System, and Rover Simulators. For my internship, I was assigned to the Camera System.

The Camera System consists of two subsystems: imaging hardware and software and compression hardware and software shown in Figure 8. The camera will be used during tele-operated mode to provide a live feed to the human drivers. It will also be used to record high-resolution pictures while on the lunar surface. The camera must be 1.3 megapixels or greater, have a low power draw 5W or less, a small form factor, a 100G or more shock-resistant rugged enclosure, capable of operating in a -40 to 85 degrees Celsius temperature window, have scalable bandwidth outputs, and utilize a standard lens mount.

METHODS
The first test done on the prototype camera was on a commercially available rover test bed with verified mobility capabilities. The rover and camera were controlled by web interface operated by servers in a remote Academy office. Packet loss and latency was controlled by the aforementioned servers. The group's hypothesis was that the image quality would degrade as packets were dropped. Ultimately, the image quality of the video feed did not change; instead the speed of the stream did slow down significantly when the amount of packet drops increased. It was concluded that additional steps needed to be taken to ensure the image quality would degrade more gracefully and maintain a more even frame rate.

![Figure 1: The Rover testbed used to simulate packet loss and driving](Photo by Adria Fung)

The second test was done through a handheld video camera connected to a computer via FireWire. A Linux-based computer running VLC Media Player served as the media streamer. With the three computers the group had at its disposal, all had some minor problem that inhibited the testing. For example, one computer had a FireWire port, but was not able to connect to another computer via Ethernet cable. The handheld video camera was removed from testing, and a laptop webcam was used instead; however, one of the computers did not recognize its own webcam when operating under Linux. This method had proven itself to be overly complex for the test required, and so additional work on this test was abandoned.

![Figure 2: VLC Media Player in Linux](Screenshot by Adria Fung)
The Camera System subgroup was tasked with determining how best to compress the driving image but still allow the human operator to drive the rover on the moon. Many different image compression techniques were tested to see whether the image could be used for driving, despite large amounts of image data being removed. The use of a black and white image instead of a color image allowed us to compress the on-disk size of each image by a factor of 24 over a raw RGB image. Additional lossless compression techniques allowed further compression. Four different methods of converting a full-color RGB image to a black and white binary image are shown.

![Figure 3: Original Image](image_url)

Photo by Camera subgroup

![Figure 4: Floyd Steinberg Dithering](image_url)
![Figure 5: Edge Detecting](image_url)
![Figure 6: Thresholding](image_url)
![Figure 7: Randomized Dithering](image_url)

Photos by Camera subgroup

**RESULTS**

Each method had significantly different results. Of the methods described, Floyd-Steinberg Dithering was chosen because it most fully represents the original picture using only two colors.

In pseudocode:

```plaintext
for each y from top to bottom
    for each x from left to right
```
oldpixel := pixel[x][y]
newpixel := find_closest_palette_color(oldpixel)
pixel[x][y] := newpixel
quant_error := oldpixel - newpixel
pixel[x+1][y] := pixel[x+1][y] + 7/16 * quant_error
pixel[x-1][y+1] := pixel[x-1][y+1] + 3/16 * quant_error
pixel[x][y+1] := pixel[x][y+1] + 5/16 * quant_error
pixel[x+1][y+1] := pixel[x+1][y+1] + 1/16 * quant_error

DISCUSSION

The Camera System is still in the development stage. Streaming the video feed over the radio is an ongoing work in progress. Fully utilizing the subsampling and compressing capabilities of the camera and frame grabber board are being investigated. Matlab is being used to explore additional compression techniques, such as Run-Length, Huffman, or LZW Encoding. It is still in discussion whether or not to compress the image in JPEG, PNG or JBIG format, or to use a video file format like MPEG or MJPEG.

CONCLUSION

Dithering and image compression have both been completed. Floyd-Steinberg Dithering was chosen because it utilizes only two colors; black and white, rather than gray scale, therefore, reducing the amount of data being sent from the moon to Earth. It proved to depict the image more truly than other techniques while requiring less bandwidth than a comparable grayscale image.

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FIGURES
Figure 8: Camera subsystem in the Rover

Drawn by NASA Ames Robotics Academy