Toward the Development of a Flexible Testbed for Research in the area of Flexible Autonoumous Machines operating in an uncertain Environment (FAME)

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Abstract

This paper describes the development of a flexible testbed for research in the area of *Flexible Autonomous Machines operating in an uncertain Environment (FAME).* The testbed developed is a robotic vehicle. Made of a strong aluminum alloy and powered by two (2) twelve volt batteries, the developed *FAME* testbed consists of (i) an onboard pentium class computer which serves as a central hub for all onboard data management, (ii) a remote command, communications, and control station that is networked to a suite of Pentium-class Windows NT Workstations, (iii) a wireless data system for transmitting sensory data to the command station and for transmitting reference commands to the vehicle, (iv) a video system for transmitting video to the command station, and (v) a flexible onboard power distribution system for addressing all power consumption requirements. Each subsystem is described within the paper. Experimentally obtained data is presented to illustrate data/video system performance. The vehicle's potential for future research in the areas of guidance, navigation, and control is also described.

1 Introduction, Overview, and Contributions

This section provides an introduction and overview of the *FAME-ROVER* project.

Main Motivation. Central to this project is the desire to develop a flexible testbed which will serve as the basis for future research in the area of

Flexible Autonomous Machines operating in an uncertain Environment (FAME).

This all-encompassing theme includes robotics and automation, autonomous vehicles, sensors and actuators, control systems, navigation systems, guidance systems, sensor enhancement algorithms, distributed computation, artificial intelligence, wireless communications, computer networks, low power circuit design, rapid prototyping,

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human-machine interfaces, hardware/software achitecture and integration.

Contributions. The FAME-ROVER Testbed has the following functionality:

- Remote Controllable via joystick
- Real Time Video System
- Wireless Data Network
- Power Distribution System
- On Board Computer
- Command and Control Computer
- Actuator and Sensing Interfaces
- Detailed Documentation of Systems

Significance of Work. The central contribution has been the development of an operational "Testbed for Research in the area of Flexible Autonomous Machines operating in an uncertain Environment (FAME)." The testbed is a mobile robotic vehicle (ROVER) with wireless data and vision capability - networked to a suite of powerful Windows NT Pentium class workstations. This testbed may be used for developing and evaluating complex guidance, navigation, and control algorithms. It can also be used as a testbed for research in any of the following areas: low and high power circuit design, vision and speech processing, multidimensional signal processing, human-machine interfaces, distributed computation, sensor development, data encryption, artificial intelligence, etc..

2 Overview of FAME Testbed: A System Perspective

The block diagram shown in Figure 1 consists of the following components:

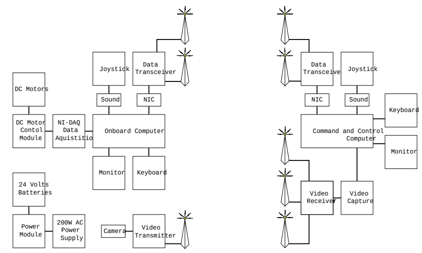

Figure 1: System Overview

Wireless Vision System is used to transmit real-time video from ROVER back to the Command Station.

Wireless Data Network is used to send actuation and sensor signals to and from ROVER to the Command and Control Computer.

Command and Control Computer is the computer that the user interfaces with. The Command and Control Computer acts as the controller of the remote vehicle. It receives sensor data from the Wireless Vision System and Wireless Data Network. It transmits reference commands over the Wireless Data Network.

On Board Computer is the computer on the vehicle. This computer acts as an interface between the Wireless Data Network and the Sensors and Actuators. The computer receives motor speeds and direction over the Wireless Data Network and translates them to voltages to give to the Motor Interfaces.

Power Distribution System provides necessary voltages and power to the vehicle's on board systems.

Actuation and Sensing Sytems is how the on board computer interfaces with ROVER's motors and other actuators as well as how the computer can receive sensor data. There are a few different interfaces that this system uses.

Mechanical Systems refers to the Chasis of the Vehicle, the Wheels, and other Structural Components of the Vehicle.

3 Wireless Vision System

The Wireless Vision System implemented on ROVER is used to send real-time video from ROVER to the remote

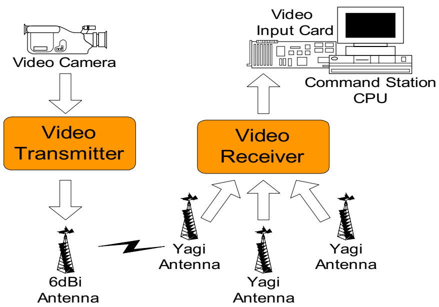

Figure 2: Wireless Video System Block Diagram

Command and Control Station. The Vision System is made up of the following components: Coherent Communications CVT-1000 - Video Transmitter (on ROVER), Coherent Communications CVR-1500 - Video Receiver (at Command Station), 6 dBi omni-directional Antenna (on ROVER), Three YA-7 Yagi Antennas (at Command Station), Low Loss Coaxial Cables, Compact Video Camera (on ROVER), and WinTV Video Capture Card (at Command Station).

Video Transmitter. The video transmitter being used in this project is Coherent Communications (www.cocom.com) CVT-1000 Transmitter. This transmitter takes an NTSC standard video signal and transmits it at 900 MHz. The power levels in this transmitter are selectable from 1 mW to 600 mW. When using the 600 mW power level and the 6 dBi antenna the transmitter has a range of 5000 feet (Line of Sight).

Video Receiver. The Video Receiver is Coherent Communications CVR-1500 Receiver. The receiver has inputs from three antennas that enables it to choose the highest power signal. The receiver has a microprocessor that is constantly determining the strongest signal in order to give the highest quality image. This allows the receiver to be used with semi-directional Yagi Antennas. The beams of the 3 antennas connected to the receiver can be pointed in different directions. Thus allowing a higher beamwidth from the array of 3 antennas than would have been if only a single antenna was connected to the receiver. This allows the use of higher gain antennas which sacrificed smaller beamwidth for higher gain.

Antennas and Cables. The 6 dBi (dBi is the gain of the antenna as compared to an isotropic antenna) antenna mounted on ROVER is a high gain omni-directional antenna. This antenna is mounted on ROVER and is connected to the Video Transmitter. The 3 YA-7 Yagi antennas are high gain antennas that are connected to the Video Receiver over 50 feet of low loss coaxial cables. The Yagi antennas are 24 dBi and have a beamwidth of 70 degrees.

Video Camera. The video camera is the PC-79 Color Inline Video Camera from Supercircuits. The video camera is small, lightweight, and easy to wire and mounted on pan/tilt mechanism as seen in figure **??**. It also comes with it's own swivel bracket and cables. The camera uses the NTSC standard which means it can be plugged into any standard monitor or recorder without special adapters. The machined case enclosing the camera makes it rugged which is necessary as ROVER will frequently be operated in an outdoor environment. The camera has 400 lines of resolution. The camera allows us a clear image even in shaded areas or on cloudy days as it has low light capabilities of 0.5 Lux (Twilight = 1 Lux). The video camera has a Field of View of approximately 78 degrees as compared to a human's 180 degrees.

Video Capture Card. The Video Capture Card used is a PCI WinTV Card. This is an inexpensive video capture card that was designed to watch TV on a computer. It has a S-Pal input connection for connecting to video cameras and VCRs. It also has coaxial input connection which is where the card is used to connect an antenna, cable-tv, or satelite connection. The video receiver is connected to the video capture card through the S-Pal port.

4 Wireless Data Network

The Wireless Data Network is used to send sensor data from ROVER to the command station and reference commands from the Command Station to ROVER. The network is Breezecom PRO.11 Wireless Computer Network (www.breezecom.com). This network is a 2.4 GHz IEEE 802.11 network that allows a data rate up to 3 Mbps. The Wireless Data Network is made up of the following components: Breezecom AP-10 Access Point - Transceiver/Wireless Hub (at Command Station), Breezecom SA-10 Station Adapter - Transceiver/Wireless Node (on ROVER), Two 6 dBi omni-directional Antennas (on ROVER), Two 8 dBi omni-directional Antennas (at Command Station), Low Loss Coaxial Cables and CAT5 10BASE-T Cables, 3Com Network Interface Cards (both on ROVER and at the Command Station), and TCP/IP Network Protocol.

Wireless Hub/Transceiver. The transceiver that is used at the command station is a Breezecom Wireless AP-10 Access Point. Both the AP-10 (wireless hub) and the SA-10 (wireless node) take advantage of a space diversity system. They are both connected to a set of 2 antennas. When they receive a signal, a microprocessor inside the

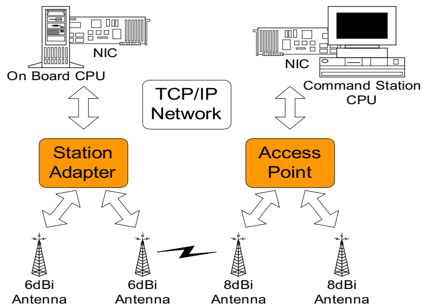

Figure 3: Wireless Data Network Block Diagram

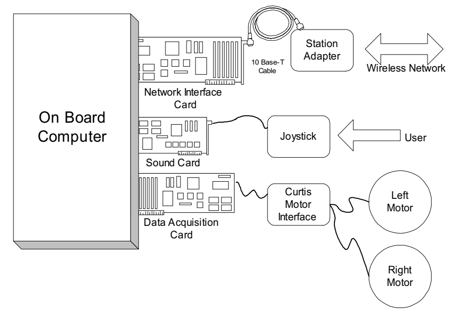

Figure 4: On Board Computer Interface Diagram

devices picks the signal with the most power. The access point is attached to the 8 dBi omni-directional antennas through 50 feet of low loss coaxial cables. The access point is connected to the Command and Control Computer with a cross over CAT5 10BaseT cable to the network interface card in the Command and Control Computer.

The Access Point is the link between a wired network and a wireless network. They manage all of the computers with Station Adapters within their range. This means that the Access Point keeps a list of network addresses of the computers that are on the wireless network. When it receives an incoming packet it compares it to the list and determines if it should pass it back onto the wired network or onto the wireless network. It acts as a Wireless Hub to the computers with Station Adapters within its range and a gateway to the wired network.

Wireless Node/Transceiver. The transceiver mounted on the ROVER vehicle is Breezecom's SA-10 Station Adapter. The SA-10 takes advantage of a diversity system as mentioned above. The station adapter is connected to the 6 dBi Omni Directional Antennas mounted on the back of the ROVER vehicle. The SA-10 is connected to the on board computer with a CAT5 10BaseT Cable. The cable is connected to a network interface card (NIC) in the On Board Computer.

Antennas and Cables. The 2 antennas mounted on the ROVER vehicle are 6 dBi Omni-directional antennas with a detachable connections to the SA-10 Station Adapter. The 2 antennas at the Command and Control Station are 8 dBi Omni-directional antennas. These anntennas are connected to the AP-10 Access Point with 50 feet of low loss coaxial cables and detachable connections.

A CAT5 10BaseT cable is used to connect a computer to a computer network. On the ROVER vehicle it is used to connect the on board computer to the Station Adapter. The crossed over CAT5 10BaseT cable is used to connect two computers (or other active devices) together. It is a crossed over cable since its read and write wires are switched from one connector to the next. If it were not switched the read line would never hear what the other computer put on the write line. The crossed wired is used to connect the Command and Control Computer to the Access Point without the use of a network hub.

Network Interface Cards (NICS). Both computers are connected to the wireless network through a 3Com Network Interface Cards (NICS). The card used is a 3Com 3C508 Network Interface Card with at least a 10BaseT connection. They are designed to be used on a 10 Mbps Ethernet Network.

Network Protocols. The Breezecom Pro.11 Wireless Network uses the Wireless Ethernet Protocol (IEEE 802.11). The station adapter and access point communicate with the computers using the Ethernet standard (IEEE 802.3). The wireless network is independent of the networking protocols that are used in the computers. The network used is a TCP/IP network.

5 On Board Computer

ROVER's on-board computer has been assembled from recycled computers. Using two computers the team built a computer featuring the following hardware and software: Baby AT style Motherboard, Intel Pentium 166 Processor, 48 MB of RAM, Caviar 1.2 GB Hard drive, 2x CD-ROM, Creative Labs 16 bit Sound Card, 3 1/2 in. Floppy Drive, 3Com 3C509 Combo Network Interface Card (NIC), National Instruments Lab-PC-1200 Data Acquisition Card (NI-DAQ), Microsoft Windows NT 4.0 Operating System, Microsoft Netmeeting, Microsoft Visual C++ Software Development Enviroment, Local Controller of ROVER Program (Developed Software), and Remote Controller of ROVER Server Program (Developed Software).

Basic Hardware. The on board computer is an Intel Pentium 166 with 48 MBytes of RAM. The motherboard has 2 IDE channels, a Floppy Drive Controller (FDC), 4 slots for SIMM (72 pin) RAM, 2 Serial Ports, 1 Parallel Port, 3 ISA card slots, and 5 PCI card slots. The Hard drive is a Caviar 1.2 GBytes Hard Drive. The hard drive is connected to the motherboard with an enhanced IDE (EIDE) interface. The Hard Drive allows the on board computer to store its operating system and programs. The on board computer has a 3 1/2" floppy drive. The floppy drive interfaces with the motherboard through the stadand FDC (floppy drive controller). The floppy drive is used to maintain and update the software on the on board computer. A double speed CD-ROM player is also mounted into the on board computer. It is connected to the secondary channel of the IDE interface on the motherboard. It is used to load software onto the on board computer. A creative labs 16-bit sound card is an ISA slot on the motherboard. The soundcard has a midi/joystick port that is used during local control of the vehicle. The Network Interface Card is a 3Com 3c509 10BaseT NIC. The NIC is used by the computer to interface with the Wireless Network.

Data Acquisition. The computer is equipped with a National Instruments Lab-PC-1200 Data Acquisition Board (NI-DAQ). The NI-DAQ is capable of sending 2 analog voltage signals between 0-10 Volts and multiple digital signals. It can also read 2 analog voltages and multiple digital signals. This allows the on-board computer to send signals to ROVER mounted actuators, and to receive signals from ROVER mounted sensors. This includes sending an analog voltage to the Curtis DC motor controllers to control the motor speeds, and a digital switch signal to determine motor directions. See section 8 for more details on the actuation and sensing systems.

The computer can also use its communications ports (Serial, Parallel, and Network) to send actuation signals and receive sensing information. The use of the Serial Ports would require some extra circuitry, such as a PIC microcontroller, to convert the serial communications (RS-232) into actuation signals and to turn sensor signals into RS-232.

Installed Software. The on board computer is running Windows NT 4.0 as the operating system. The operating system manages the resources of the computer, especially the memory and network connection. A monitor, keyboard and mouse can be connected to the on board computer and the user can interface with the computer like a normal desktop computer.

Microsoft Netmeeting version 3.0 was installed on the computer to give remote access to the desktop. Netmeeting has a side program called Remote Desktop Sharing (RDS), that allows another computer running Netmeeting to connect to the RDS over a network and use the Desktop of the remote computer. This allows a user to work with the on board computer without connecting a monitor and keyboard, but instead using a network. This provides a means to start programs and manage the on board computer remotely.

Microsoft Visual C++ Software Development Enviroment is installed on the on board computer to compile the programs necessary to run the vehicle. It provides all of the standard Microsoft MFC libraries for use in the programs developed to control ROVER.

Local Controller of ROVER Program. The Local Controller Program polls the joystick for current position and button status. It then converts the joystick position and button status into left and right wheel speeds and directions. The wheel speeds and directions are sent to the curtis motor controller using the NI-DAQ board. It repeats this process at a rate of 100 Hz. This program allows the user to drive the ROVER vehicle directly from a joystick connected to the on board computer and does not require the wireless network.

Remote Controller of ROVER Server Program. The Remote ROVER Controller Program is run on the command and control computer. Therefore the on board computer has a Controller Server Program which interfaces with the Remote ROVER Controller Program that is running on the command and control computer. The Server Program listens to a port on the network for a connection request sent from the Remote Controller Program. When it hears a connection it opens a new port on the network, that is not already being used, and returns to the port address to the Remote Controller running on the command and control computer. Once this connection has been made the two programs can use this port as a data pipe that will deliver data in both directions. The bidirectional flow of data allows both sensor data and reference commands to be sent across the network. Once the Server Program has received a wheel speed reference command from the Remote Controller it then determines a voltage corresponding to that speed and sends the voltage to the curtis motor controller using the NI-DAQ board. When the Remote Controller breaks the connection to the Server the Server will send a stop signal to the Motors.

6 Command and Control Computer

The Command and Control computer has the following hardware and software: AT style Motherboard, Intel Pentium Pro 200 - Processor, 48 MB of RAM, 4.8 GB Hard drive, CD-ROM, 16 bit Sound Card/built into the motherboard, 3 1/2 in. Floppy Drive, 3Com 3C509 Combo Network Interface Card (NIC), Video Capture Card, Microsoft Windows NT 4.0 Operating System, Microsoft Netmeeting Program, Microsoft Visual C++ Software Development Enviroment, and Remote Controller of ROVER Program.

Basic Hardware. The Command and Control computer is an Intel Pentium Pro 200 with 48 MBytes of RAM. The motherboard has 2 IDE channels, a Floppy Drive Controller (FDC), 4 slots for SIMM (72 pin) RAM, 2 Serial Ports, 1 Parallel Port, 3 ISA card slots, and 5 PCI card slots. This motherboard also has built in ports for video, sound, and a game port. The Hard drive is a 4.8 GBytes Hard Drive. The hard drive is connected to the motherboard with an enhanced IDE (EIDE) interface. The hard drive allows the computer to store its operating system and programs. The command and control computer has a 3 1/2" floppy drive. The floppy drive interfaces with the motherboard through the stadand FDC (floppy drive controller). A CD-ROM player is also mounted in the command and control computer. It is connected to the secondary channel of the IDE interface on the motherboard. The Network Interface Card is a 3Com 3c509 10BaseT NIC. The NIC is used by the command and control computer to interface with the Wireless Network.

Video Capture Card. The Video Capture Card is a WinTV Go Video Input Card. The card is designed to watch TV while working on a computer. This card comes with programs that allow you to select what channel the user is watching. The only channel used is the direct Video In port. The card and software can also be used to take still images and save them as jpeg files on the computer. The ability to record video is limited to less then 15 frames per second. VCR quality is approximately 30 frames per seconds therefore this card doesn't have the ability to save video at an acceptable rate. Therefore if video is to be analyzed by them computer in the future, a different video capture card will be necessary.

Installed Software. The command and control computer is also running Windows NT 4.0 as the operating system. Microsoft Netmeeting version 3.0 was installed on the computer to get remote access of the on board computer's desktop. Microsfot Visual C++ Software Development Enviroment is installed on the on board computer to compile the programs necessary to run the vehicle. It provides all of the standard Microsoft MFC libraries for use in the programs developed to control ROVER. This is the enviroment in which the three high level programs where developed in. Visual C++ is an object oriented language, so when an object has been developed the programmer only has to interface with that object in order to use it.

Remote Controller of ROVER Program. The Remote ROVER Controller will be running on the command and control computer. The Remote ROVER Controller connects to the Remote ROVER Controller Server Progam over the network. Once connected a flow of data can be sent in both directions. This allows both sensor and actuator information to be sent across the network. The Remote Controller program generates wheel speed commands by polling the joystick position and button statusand then translating it to wheel directions and speeds for both the left and right wheel. These wheels speeds and directions are then sent across the network to the Server Program. The Server Program then delivers these commands to the motors. This process is repeated at a rate of 100 Hz.

7 Power Distribution System

A power supply and distribution system has been developed to provide the variety of DC voltages required by ROVER's on-board computer and wireless communications systems. The power requirement of each of the on-board systems was computed and totaled so that adequate power is supplied. The power supply needed to be expandable to allow for future additions to ROVER's sensory and actuator components.

The ROVER Power system consists of the following main components: AC/DC computer power supply, modified to supply output voltages of ± 5, ± 12 volts to the power control module, 24 Volt DC supply from two 12 volt marine batteries connected in series mounted under the DC Motors, Power control module mounted centrally on ROVER, and a computer power distribution box mounted inside on-board computer case.

The designed Power System provides on/off switching and power source selection. The power system can run from 2 different sources: a 24 volt DC power source from two 12 volt marine batteries or an AC to DC power supply connected to a standard 110 volt AC wall outlet. The DC motors are powered exclusively from the 24 volt bat-

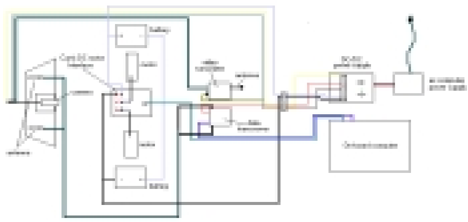

Figure 5: High Level Wiring Diagram ROVER systems

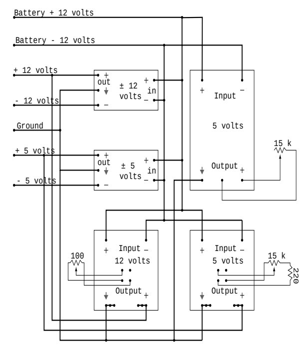

Figure 6: Power Control Module

tery supply. The AC power source is used to power the on-board computer and other electronics during software while working on the on board computer in the laboratory.

The system supplies power to ROVER's on-board computer, DC motors, wireless transmitter/transceiver, as well as additional sensor/actuator circuitry. The power system distributes appropriate voltage supplies to all ROVER mounted electronic components through the appropriate wiring and wiring connectors as depicted in the wiring diagram in Figure 5. Wiring has been color coded in the following manner wherever possible to indicate the appropriate voltage supplied: Red = +5 volts, Yellow = +12 volts, Blue = -12 volts, White = -5 volts, and Black = common (ground).

Power Sources. The two 12 volt marine batteries are connected in Series to give a single 24 volt DC source. This 24 volt source is then used by the Motors, Curtis Motor Interfaces, and the Power Control Module. The electronics get their power through the Power Control Module, when running on the DC Battery.

There is an AC Power Supply that converts power to all the standard Voltages that electronics and computers use ($\pm 12V$, $\pm 5V$). This AC power supply can be plugged in when ROVER is being worked on in the lab. This allows the user to work on the on board computer and electronics without draining ROVER's two 12 volt marine batteries.

Power Control Module. Power to all electronic equipment, except the DC Motors, is switched ON/OFF from the Power Control Module. The power source is also selected by another switch on the ROVER power module. The power source switch can only be changed when the power module is in the OFF position. If it is changed when the power module is in the ON position the power is briefly interrupted and the computer and other electronics will reset. When switched OFF, the power module can be set to run from either the DC or AC source. The power control module contains the following components: ON/OFF switch, AC outlet/DC battery power selector switch, 5 DC/DC power converters, Power indicator LED, Cooling Fan, Power distribution connector strip.

The designed Power Control Module uses five DC/DC converters giving a variety of output voltages. These DC/DC power converters are used to convert the 24 volt input into the four voltages of used by ROVER's hardware: ±5 volts DC, ±12 volts DC. ROVER's hardware is estimated to require 57 watts of power at +5V, 1 watt of power at -5V, 24.9 watts of powere at +12V, and 2 watts of power at -12V. The purchased DC/DC converters are contained in the Power Control Module and are manufactured by Astec America (www.astec.com) and Lambda (www.Lambda.com). The wiring inside the power control module is pictured in Figure 6.

The DC/DC power converter output voltages are adjustable by potentiometers and resistors connected to the sensing pins on the Astec modules, and the voltage output pins on the Lambda modules. The potentiometers allow the output voltages to be tuned in circuit to provide the exact voltages required.

8 Actuation and Sensing Systems

Curtis DC Motor Interface. ROVER is equipped with a pair of Curtis DC motor interfaces. The Curtis DC motor interfaces are designed to take the 24 volt input from the two 12 volt batteries and supply output voltage directly to the DC motors. The output voltages are determined by separate control inputs on the Curtis motor interfaces. The control inputs range from 0 volts to 5 volts input to indicate speed, and a switch (open / close)

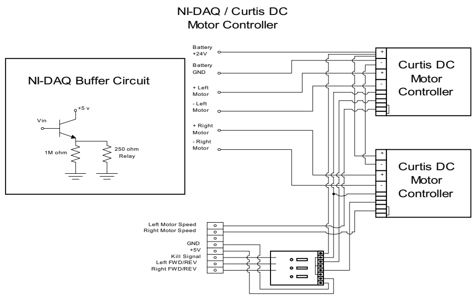

Figure 7: Curtis DC Motor Controller Interface

input to indicate direction, either forward or reverse.

National Intstruments Data Acquisition Board (NI-DAQ). The NI-DAQ can be used for both sensing and actuation. It has 2 input and output analog voltages that can range from 0 to 10 volts. It also has a many digital inputs and outputs. With the analog inputs a motor speed can be sent to the Curtis Motor Interface. And with the digital outputs a logical state can be sent to an actuator. Such as forward or backwards can be sent to the Curtis Motor Interface. Since the NI-DAQ has many remaining Digital outputs they could be used to drive other actuators in the future.

The NI-DAQ board provides the 2 analog outputs and 3 digital outputs that are used. The analog outputs range from 0 and 5 volts commanding the left and right wheel speeds with, 0 volts equivalent to the motors are stopped and 5 volts equivalent to full speed ahead. The digital outputs switch 3 relay circuits using an NPN transistor and 5 volts power supplied by the NI-DAQ board. The first 2 relay switches control left and right forward/reverse directions and the 3rd relay switch controls the kill switch. The kill switch must be closed to activate the Curtis boards, thus power loss to the computer, and subsequently the NI-DAQ board will stop the vehicle's motors. Figure 7 shows this motor interface to the on board computer.

Serial Digital/Analog Interface. The on board Computer has 2 serial ports. These serial ports use serial RS-232 communications. With the use of a PIC Microcontroller RS-232 commands can be translated into voltages and signals. The analog voltages are created using Pulse Width Modulation.

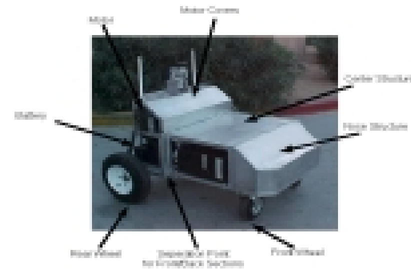

Figure 8: Mechanical Components of Rover

9 Mechanical Systems

Chassis. ROVER's Chassis is made of lightweight hollow, square, aluminum tubing welded together. It was built to support 350+ pounds. In the interests of keeping the robot transportable, the frame is quickly separable through the employment of quick release fasteners. Dzus fasteners were used to make it easy to remove the aluminum skins from the frame.

Added Structural Components. As numerous systems were added to ROVER, there was a need to augment the ROVER vehicle structure in order to mount these systems. These structures were fabricated by the ASU machine shop. The following structures were added.

Nose Structure. This structure was added mainly for asthetic reasons, however, there is always the possibility of using it to mount components in the future.

Center Structure. This structure was added for mounting purposes. It houses the on-board computer, the power control module, and has room for future mounting of components on its flat, top surface.

Motor Covers. This structure was added to provide a covering for the DC motors and a surface for mounting the necessary antennas and the camera. As this structure is completely enclosed, there is an access door located in the center of the back panel. This door gives access to the DC motor interface mounted underneath.

Wheels. The front wheels are 8.5 inch caster wheels that have a swivel radius. These wheels are free turning hence the speed of the back wheels controls the direction of travel.

The rear wheels are 15 inches in diameter, have 3.5 inch tread, and a 9 inch inside rim. Each rear wheel is attached to a DC motor for propulsion and turns on its own axle. Consequently, a change in direction for ROVER is achieved by sending different torques to each wheel. This

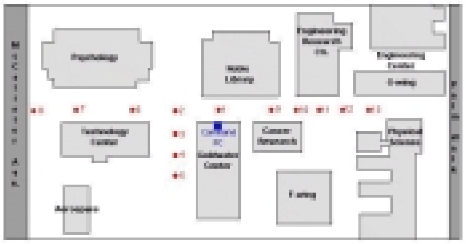

Figure 9: Map of Outdoor Locations used in Testing of Wireless Systems

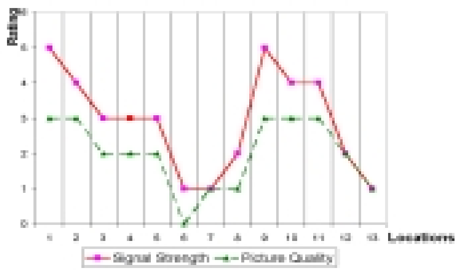

Figure 10: Plot of the Signal Strength and Picture Quality at Various Locations

is accomplished through the use of a Curtis Motor Controller for each DC motor.

10 Experimental Data

Test For The Wireless Video System. Testing of the video system verified that the system transmits clear video images over a range that both meets our needs and conforms to advertised specifications. Testing was conducted in an outdoor campus environment. These tests determined the systems abilities, strengths, and weaknesses. The Command Control Station was set up in the closed Goldwater Center (GWC) Lobby. ROVER was driven to different places on the sidewalk on both the south and east sides of GWC. Depicted in Figure 9

At each location described by the map in Figure 9, various readings were taken and a still image captured. These results are summarized in Figure 10. The quality of the images were rated for each location in the following way: Good = clear image, Fair = slightly fuzzy image, Poor = grainy, fuzzy, ghost images. In order to plot the quality, a value between 0 and 3 was assigned to each image in the following manner: Good = 3, Fair = 2, Poor = 1, and No Image = 0. The Signal Strength was measured off of the Receiver and given a value from 5 (Strongest) to 1 (Weakest).

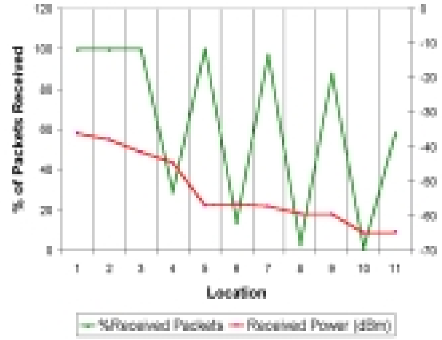

Figure 11: Received Power and Percentage of Packets Received at Various Locations

Observation:. When testing outside, the system was able to transmit a clear signal from approximately 100 yards away. After this distance, the image became slightly fuzzy; however, ROVER could still be controlled wirelessly for another 25 feet. As wireless control for longer distances is desired, the higher gain antenna will be extremely useful in transmitting a clearer image for longer distances. With this antenna, ROVER will be able to venture approximately 5000 feet away from the command and control station.

Test For the Wireless Network. Testing of the wireless network verified that the wireless network transmits data over a range that both meets the needs and conforms to advertised specifications. Testing was conducted in an outdoor campus environment. These tests determined the systems abilities, strengths, and weaknesses, and enabled the decision of whether to use this system or purchase a new one. The Command and Control Station was set up outside the GWC Lobby. ROVER was located at a position 200 yards down the sidewalk from the command control station.

Observation:. The wireless network performed as expected. The line of sight transmission was excellent. The power of the signal decreased with distance as expected. The ratio of successfully received packets also decreased with distance. The decrease in the ratio in received packets will cause a reduction of the bandwidth available to the wireless network.

11 Summary and Directions for Future Research

This paper has described the development of a flexible testbed for research in the area of *Flexible Au-*

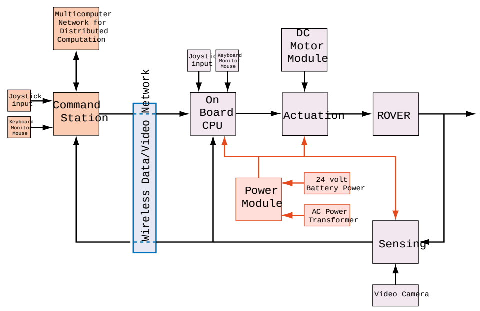

Figure 12: System Block Diagram

tonomous Machines operating in an uncertain Environment (FAME). The testbed is a mobile robotic vehicle (ROVER). With its high performance wireless data and vision systems, onboard computer, remote command and control station networked to suite of Pentium-class Windows NT Workstations, the developed testbed will permit research in the areas of vision, distributed computation, real-time optimization, data fusion, guidance, navigation, control, artifical intelligence, human-machine interfaces, and many other areas. Future work will focus on making ROVER autonomous.

Efforts to build other *FAME* testbeds are underway [1]. These include a small robotic vehicle, a large robotic (tank-like) vehicle, and a blimp. The goal is to achieve coordinated navigation of these air- and ground-vehicles around the ASU main campus.

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