ADAM II

An IGVC Robot

IGVC 2006

Bob Jones University

Introduction

ADAM II is an autonomous robot designed for the IGVC by a team of engineering students at Bob Jones University. ADAM II has been updated for the 2006 IGVC from its original design which competed at the IGVC in 2005. The updated version of ADAM represents significant improvements in mechanical and electrical design as well as increased functionality over the 2005 model. The redesign was completed as a requirement of students in the Ele-406, Embedded Systems class.

In contrast to many IGVC teams, the methodology underlying our design decisions encourages a minimal dependence on exotic technologies with a long term goal of creating an autonomous vehicle which only uses passive sensors. Benefits to this approach include increased appeal in military applications where active sensors such as laser range finders could alert the enemy to the presence of the vehicle and where jammed GPS signals may result in an inoperable vehicle. In addition, reducing reliance on exotic sensors often makes the vehicle more cost effective and reliable.

As a design team, we followed the design process which is laid out in Ertas and Jones book, *The Engineering Design Process*. The process given in this text is as follows: Recognition of need, Conceptualization, Feasibility assessment, Assignment of organizational responsibilities, preliminary design and detailed design with feedback leading to redesign if necessary.

Innovations

In order to gain precise location information with a very rapid update rate without relying on an extremely fast GPS receiver, we developed an optical navigation system, or optical odometer. This optical navigation system uses a CMOS image sensor often used in high-end optical mouse applications to track the movement of the ground underneath the robot. The optical navigation system provides the vehicle with rapid updates of the distance it has traveled. The optical navigation system allows the vehicle to navigate accurately during short GPS outages.

A new approach to robot control was chosen for ADAM II, and approach we call "horse and rider." Just as a horse and rider both have intelligence and different spheres of expertise with which the cooperatively control their travel, so ADAM II was given a laptop "rider" with it's own video camera for high level control. The on-board "horse" processor handles all of the low level control. The two processors communicate using JAUS messages over Ethernet. The "horse" alone is capable of reactive control, and the "rider" implements deliberative control.

Design Process

Recognition of Need: The need to complete a comprehensive redesign of ADAM was created because it was a requirement of Ele-406. Though this may appear to be an artificial need, the requirements for a vehicle to be successful in competing at the IGVC reflect the requirements of autonomous vehicles that are found in real-world scenarios such as unmanned ground vehicles (UGV).

Conceptualization: Because the design team began with a functioning vehicle which competed at the IGVC in 2005, the design process began with a review of ADAM's performance at the IGVC. The team quickly began to focus redesign efforts on the areas where ADAM II had shown some weakness in its past performance. The major areas for improvement that were identified included, increase the video camera's range of view, improve reliability of electrical wiring, enhance obstacle avoidance, improve the vehicle's ability to drive over sand and ledges, and add JAUS capability.

Feasibility assessment: In considering the proposed changes to ADAM II, feasible designs had to not only comply with IGVC specifications for the vehicle, but also had to lie within our budget restraint of $1000.

Assignment of Organizational responsibilities: To effectively accomplish the proposed redesign of ADAM II, each member of the design team was assigned specific tasks. Though team members frequently worked together, each team member was expected to manage his assigned tasks. Because some tasks cannot begin until other tasks have been completed, task interdependencies were determined, and a master schedule was created to facilitate on-schedule completion of the redesign. A website and online forum dedicated to the project helped team members stay updated on the project and any current issues.

Team Members	Primary Area of Responsibility
Keith Kimbrough (Senior, EE)	Compass, E-stop, code
Daniel Garalde (Senior, EE)	Camera, Code
Chris Ryan (Senior, EE)	Re-wiring, Hardware
John Bergin (Senior, EE)	Structural design
Philip Herwaldt (Senior, EE)	Performance predictions, Report
Mark Calnon (Senior, Computer Science)	Computer Programming

Preliminary Design: Figure 1 shows a block diagram of the preliminary design.   Figure 2 shows a functional diagram of the JAUS system implementation. Details of the preliminary design are described in the following sections.

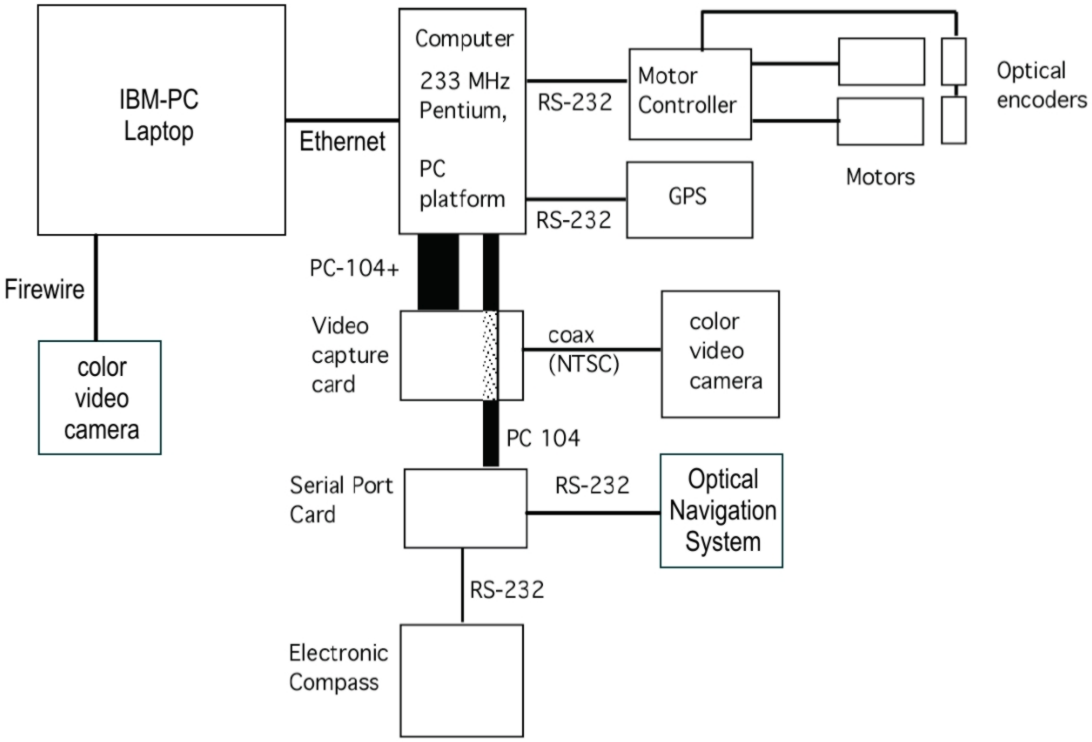
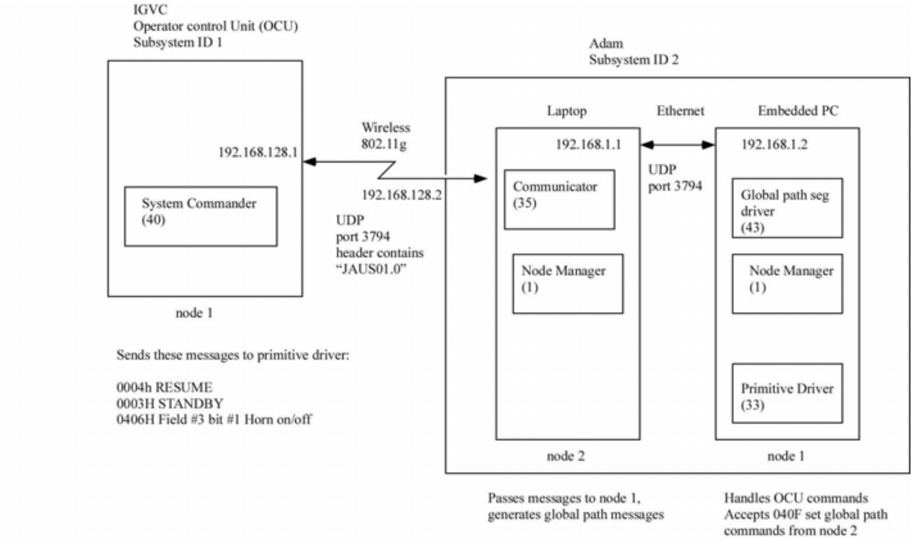


Figure 1: Preliminary Design Block Diagram



Sends these messages to primitive driver:

0004h RESUME
0003H STANDBY
0406H Field #3 bit #1 Horn on/off

Passes messages to node 1,
generates global path messages

Handles OCU commands
Accepts 040F set global path
commands from node 2

Figure 2: JAUS Functional Diagram

Chassis: The redesign of the chassis focused on three major improvements. First, the structural rigidity of ADAM's frame needed to be improved. The rigidity of the chassis was greatly increased by adding aluminum braces at critical points in the structure. Second, a new mounting structure for the video cameras had to be designed and installed. In order to achieve a better range of view for the video cameras, the team calculated that the cameras should be relocated toward the rear of the vehicle. In addition the camera should be raised as high as possible while satisfying IGVC height requirements. A removable steel structure was built to allow optimum mounting of the cameras. Other system components such as the wireless e-stop and GPS receiver were also mounted on this structure. Third, the chassis had to be modified to accommodate the mounting of a larger caster wheel.

Processor: The overall approach taken by the team is to divide the vehicle's computational processing into two levels of abstraction which can be handled by either the laptop or the embedded computer. The laptop executes the processor intensive deliberative control as well as environment mapping functions and sends high level navigation commands to the embedded computer. Using an industrial embedded computer, the robot executes low level control of the hardware on the vehicle and performs reactive navigation. Together the two processor systems are better than either alone.

At the beginning of the project, ADAM was running an Ampro embedded computer for low level control. However, the embedded computer failed at the beginning of the semester which caused problems throughout the design process as the team sought to move forward. Our team considered many different options such as replacing the processor with a laptop, a rugged industrial touch-screen computer and switching to a different processor board. A decision matrix was used in order to determine the best solution. The following factors were taken into consideration when determining the type of processor we would use: the cost to obtain the processor, repair if the processor should fail, power requirements, built-in ports, availability of the processor to our team, time required to make the transition, availability of a keyboard, and the need for a monitor. After working through the decision matrix, the decision was made to send in our Ampro board for repair while running ADAM on a spare Ampro board to facilitate continuation of the redesign.

Drivetrain: The drivetrain received some significant changes from the previous year. Based on poor performance by the previously used foam-filled tires, our team decided that it would be best to change the tires on our robot. We wanted a solution that would increase the robot's ability to climb small ledges as well as make it capable of driving through sand. Our team brainstormed about different options that we should consider for improving our robot’s mobility. The team settled on changing to common air-filled tires. This proved to be the simplest and most effective way of accomplishing our objective.

Compass: The compass received much attention in the preliminary design. The main problem with the compass was its inaccuracy due to the vibration of the robot. Enabling the built in IIR filter that came standard with the compass helped solve this problem. The IIR filter solved the problem of inaccurate heading measurements and smoothed out the compass reading.

GPS: The most significant change to the GPS system was that the GPS driver software was rewritten to allow the navigation software to run faster. The GPS receiver itself was moved to the camera structure in order to obtain a better, more consistent reading.

Electrical System: The reliability of the electrical system was enhanced. The new design replaced screw terminal connections with Molex connectors at key locations to allow for quick, reliable electrical connections. Digital volt meters were permanently added to both the 12 volt and 24 volt systems. Current meters were added to both the motor drive and electronic control systems. The main electronics enclosure was also redesigned for greater electrical reliability.

Performance Predictions: See Table 1 for details. ADAM II was predicted to weigh around 151 lb, but subsequent design decisions including larger wheels and tower raised the weight to 180 lb. Weight distribution is an ideal 33% per wheel. Center of mass is a low 12 inches.

Batteries are rated at 18 Ah, providing almost one hour of constant drive time at the typical maximum load. According to calculations, the robot will need approximately 4 amps at 24 volts to produce the needed 90 watts of power for the motors on flat terrain. The batteries provide about 4.5 hours of run time with this current draw. When the robot is running on a 15 percent slope, the needed power is 351 watts, drawing about 14.6 amps at 24 volts. The electronics package of this robot draws a calculated 2.67 amps of current. The 18 Ah battery should provide a run time of approximately 6.7 hours.

We plan to run our software at a 1/15 second frame rate in reactive mode, providing a reaction time of 0.067 seconds. At 5 mph, the robot moves approximately .149 meters between frame. The camera views 9 meters ahead, providing adequate time to respond to obstacles even at full speed. Deliberative mode is expected to require a much slower frame rate, so we plan to operate at speeds much slower than 5 mph when in this mode.

Table 1 - Performance Details

Parameter	**Prediction**	**Actual**
Top Speed	8.38 mph	5 mph*
Weight	151 lb	180 lb
Power (level)	90 watts	96 watts
Power (15% slope)	351 watts	360 watts
Current (24v battery pack)	3.76 amps	4 amps
Current (12v battery)	2.67 amps	1.4 amps
Weight Distribution (front/rear)	70/30	67/33 **
Battery Life (level Ground)	4.5hr	>2 hours ***
Reaction time	67ms	143 ms****
Distance of Obstacle Detection	9m	8.5m

* The drive train is capable of >8 mph on level ground but the closed loop speed controller limits the maximum speed to 5 mph.

** With two wheels on the front, this represents a distribution of almost exactly 33% per wheel.

*** Not tested all the way to dead batteries

**** Hardware is capable of 67ms frame period (15 Hz) but software has only achieved 7 Hz so far.

Detailed design: Once the preliminary design process was completed, our team moved on and began reconstruction of the robot. Included below is a more detailed description of the work that was done on the robot, as well as general information about the robot.

Frame and Chassis: The robot's main frame is constructed from extruded aluminum T-slot material supplied by 80/20, Inc. This material provides ease of assembly as well as high strength. The batteries and motor controller are mounted on a large piece of aluminum sheet metal. The rear caster wheel is mounted on aluminum angle iron anchored on either side of the robot frame. The front wheels and motors are fastened with custom mounting plates. The majority of the electronic equipment is housed in a rebuilt electronics case. Padding is used to prevent vibration problems with some of the heavier equipment, such as the batteries. Also, foam padding was used to help keep the electronics box from the effects of the vibration of the vehicle. A major improvement made this year was the addition of a tower to provide better camera placement. The tower is constructed out of rigid piping and is fastened to the top of the robot. The devices mounted on this tower include a camera, compass, and the wireless e-stop antenna. One of the main problems with the camera from the previous design was that it could not see down close to the front of the robot. Placing the camera on top of the tower gave a much better view of the front of the robot.

Electrical System: The electrical system of our robot consists of the following components: two motors, a motor controller, three batteries, a single board computer, emergency stop system, GPS receiver, compass, voltmeters, amp meters and video cameras. The single board computer is the center of the whole electrical system. It coordinates the electrical equipment for the operation of the vehicle. Most of the electrical components are located in an electronics case. The entire electrical system was removed and improvements were made to the reliability and neatness of the wiring. Our team created a permanent and professional housing for the on board computer and the system's voltage regulators. Another benefit of these improvements is the overall neatness and accessibility of the electrical box. Two amp meters were added to measure the load on the 12 and 24 volt batteries. Alongside the "ON" switch for the robot were placed two LCD displays which show the voltages across both the 12 and 24 volt batteries. This enabled us to know quickly when the batteries need charging and to get complete usage out of each battery.

Motors: The motors for this robot are modified wheel chair motors with attached gearboxes (NPC-R82) from NPC robotics. Since the motors are for wheel chairs, they are mounted on the front of the the robot just as they would be on a wheelchair. This design keeps the majority of the robot weight on the motor shafts and helps prevent the robot from tipping forward since the robot body is already on somewhat of a forward tilt. The addition of a larger caster wheel on the rear of the robot supplies sufficient support and easy maneuverability, as well as the ability to climb up larger slopes and obstacles. Our robot can now climb steps of up to 6 inches in height an improvement from 3 inches.

Motor Controller: The motor controller for the robot (NPC-AX2550) is from NPC robotics. This controller manages motor speed using PWM techniques and supports a closed-loop feedback through optical encoders. The controller communicates with a host computer via an RS-232 interface.

Batteries: Three 12-volt gel-cell batteries (PS12180) are used to power the robot. Two of these batteries are connected in series to supply 24 volts to the motor controller. The remaining 12 volt battery is used to power the computer and other electronic devices. Components in the vehicle that run on 5 volts are powered from the 12 volt system through a high-efficiency +5V DC-DC converter.

Emergency Stop System: Two options for activation of the emergency stop system are built into the robot. The first is a wireless system; the robot can be stopped using this system from a distance of at least 50 feet away. The wireless receiver has been moved from inside the robot to a position on the main tower, so as to enable better reception of signals. The second option is a simple red push-button located toward the rear of the robot. Both of these systems activate the motor controller's built-in e-stop capability.

Single Board Computer: The robot is controlled by an Ampro LittleBoard P5V PC-104 single board computer which comes equipped with an Intel Mobile Tillamook Pentium 266 CPU and 256MB of memory. The LittleBoard computer has a daughterboard that provides PS/2 keyboard and mouse input connectors and two USB ports. The LittleBoard itself includes PC type I/O.

As was discussed in the preliminary design section for the processor, the team considered different options when the Ampro board failed at the beginning of the project. The team concluded that it would be best to continue using the Ampro board. The faulty board was sent in for repairs and the redesign project was completed using an identical backup Ampro board.

Auxiliary Navigation (GPS and Compass): A serially interfaced Garmin GPS-18 LVC receiver (WAAS enabled) allows the robot to determine its current position and destination coordinates. A serially interfaced PNI TCM2 3-axis digital compass gives bearings to help supplement GPS navigation. The GPS system is accurate to within 3 feet. The GPS driver software was enhanced to allow for quicker execution of ADAM’s navigation software. The rewritten driver uses a new algorithm which stores the last position coordinates received from the GPS, and immediately returns these stored coordinates to the navigation software in the event that a new coordinate is not yet available instead of waiting for a new coordinate from the GPS receiver. The GPS receiver itself was moved to the camera structure in order to obtain a better, more consistent reading. To improve the stability of the digital compass, a built-in IIR filter on the compass was activated. This helped to drastically reduce the fluctuation in compass headings from around 20 degrees to 2 or 3 degrees. This enabled a much more accurate reading on the actual heading of the robot. The compass driver software was also improved.

Video (Camera and Video Capture Board): A NTSC color video camera and an RTD Embedded technologies CM7326ER PC-104 video capture board are used for imaging and obstacle detection. The video capture board handles both the PAL and NTSC video standards with variable frame rates and capture resolutions. It also supports multiple video channels leaving open the possibility of stereo vision in the future. This year, a second, higher resolution camera was added. This additional camera is connected to the on-board laptop to allow for greater image processing power. Brackets for mounting the cameras are attached to the tower. The mounting brackets allow for the use of wide angle lenses on the cameras.

Software: All the programming code to run the robot is written in C and C++. The software for the GPS navigation as well as the compass and GPS drivers were rewritten. The software that runs the actual navigation of the robot will be discussed in greater detail below.

Figure 3 - Raw image

Figure 4 - Processed

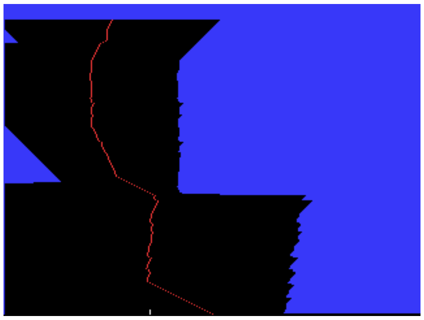


Figure 5 - Free space

Algorithms

Autonomous Challenge: Two main approaches are used in autonomous navigation: reactive and deliberative. Reactive approaches typically run faster but are known to fail in complex environments. Deliberative approaches handle a much wider arrangement of environments but require intensive computation, which make them difficult to do in real time. For our robot, we use a combination of both reactive and deliberative mode. When the path ahead is largely clear and there is an obvious path with only peripheral obstacles, we drive fast in simple reactive mode. When our quick and simple image analysis fails to reveal a clear and obvious path, we slow down and drop into deliberative mode.

Reactive Mode: Our reactive mode is based on avoidance of orange, yellow, and white color hues. These colors are identified pixel by pixel, a smoothing algorithm is applied to reduce nose, and then a trapezoid of free space is computer at the bottom center of the screen. The robot steers toward the center of the trapezoid (Figure 3-5). The chief limitation of this algorithm is the possibility of driving through gaps in the lines, a possibility that we minimize by a built-in preference toward the center of the free space and by the trapezoid free-space approach which naturally extends lines parallel to the direction of motion. When the deliberative mode is operational, we also use its preferred trajectories when possible. Properly marked potholes are naturally avoided. A dead-end will drop the robot out of reactive mode into deliberative mode, which will then be responsible for recovering form the dead-end.

Deliberative Mode: The software builds a 2D world model of the course and records the path of the robot. Upon reaching a dead end, the robot reverses its path until an alternate path is found.

Navigation Challenge: Waypoints are visited in the order they are entered by the operator. The navigation algorithm addresses two conditions. The first condition is when no obstacles are detected in the immediate path. The robot computes the heading to the next waypoint based on current GPS position, and then steers in the appropriate direction to achieve that heading. The second condition is when obstacles are detected in the path of the robot. The reactive algorithm is used to steer around them, after which the robot returns to the navigation algorithm. WASS limitations restrict the accuracy of arrival waypoints to within three feet, confirmed by testing. This is more than sufficient to meet the 2 meter requirements set forth by IGVC.

Safety Safety improvements include increasing the range of the wireless e-stop system by moving the e-stop receiver to the camera tower. The robot could then be stopped by wireless link from well over 50 feet away. Along with the wireless e-stop, a red push button is located on the rear of the robot; a simple touch will immediately shut down the robot. The robot motor controller contains the needed integrated e-stop capability and provides the braking necessary to stop the robot within the required stopping distance. In addition to the e-stop systems, foam bumpers on the front and rear of the robot provide an additional measure of safety for bystanders and obstacles. Main power supplies are fused. Batteries are sealed lead-acid with valve-regulated sealed construction and therefore have limited emissions and may be inverted without danger. A keyed main power-up switch prevents non-qualified personnel from powering the robot.

Reliability and Durability: The motherboard is temperature resistant, vibration tested, and reliability rated by the manufacturer. The air-filled tires provide a more stable platform than the previous foam filled ones and are constructed to be puncture resistant. Batteries are sealed for long life. Major components including the processor and batteries are mounted with shock-absorbing materials. Easily-removable, completely enclosing body panels provide protection from the elements. The motor controller includes both overcurrent and overheating protection.

Efficiency: A high efficiency DC-DC converter provides the main +5V power supply. A high-efficiency motherboard includes a low-power Tillamook CPU, contains no fans, has no rotating media, and only +5V power requirements. Unused systems (e.g. the printer and USB ports) are powered down for further power savings. The system is run without a monitor except for setup and testing. The motor controller includes high-efficiency multiple-MOSFET power output stages and is rated at 120A per channel with no cooling fan - with a weight of 3.8 lb, it is the lightest in its class and perfect for a robot like Adam.

Bill of Materials Because of budgetary restraints, careful planning went into every piece of material that was bought. The cost of all proposed designs was considered before one was selected, with low cost being the key factor in many of those choices. Creativity was a requirement for the team; keeping a solid design with inexpensive parts is a task that is difficult to accomplish. All the costs that our team put into the robot are listed in detail below. The actual retail cost is compared to the price for which we obtained the part.

Table 2 - Cost of Components

Components	**Quantity**	**Retail Price**	**Cost to Team**
PS12180 18Ah batteries	3	$144	$144
Ampo Littleboard Pv5 single board computer	1	$995	$995
NPC-R82 motors	2	$570	$570
Hubs	2	$40	$40
NPC-AX2550 motor controller	1	$94	$94
Wheels and tires	2	$495	$495
GPS receiver	1	$89	$89
PNI-TCM2-20 Digital Compass	1	$699	$0
PC-104 4-port serial board	1	$149	$19
T-slot and angle bracket frame	N/A	$180	$180
Emergency stop system components	N/A	$70	$70
CM7326ER PC/104 video capture card	1	$455	$455
NTSC video camera	1	$15	$15
Firewire camera	1	$120	$120
Thinkpad computer	1	$1,500	$0
Optical odometer (research project)	1	N/A	$100
Miscellaneous	N/A	$170	$170
Total		**$5,786**	**$3,557**

Certification of design work performed by the Bob Jones University design team

I, Dr. Bill Lovegrove, Professor of Electrical Engineering at Bob Jones University, certify that the members of this engineering design have done significant engineering design work on the robot that is equivalent to the work that is awarded credit in a senior design course.

Signed:

Date: