United States Military Academy

2004 Intelligent Ground Vehicle Competition

Design Report

Multi-Sensory
Autonomous
Ground
Vehicle
Intercollegiate
Competition

MAGIC Junior

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1.0 Introduction

MAGIC, **M**ulti-sensory **A**utonomous **G**round vehicle **I**ntercollegiate **C**ompetition, is the United States Military Academy's 4th time participating in the Intelligent Ground Vehicle Competition at Oakland University in Rochester Hills, Michigan. This year West Point's newest robot, MAGIC Junior, will compete in the Design Competition and the Autonomous Challenge, but has opted out of the Navigational Challenge.

MAGIC Junior was designed and built with the effort of sixteen cadets representing three different academic departments: the departments of Civil and Mechanical Engineering, Electrical Engineering and Computer Science, and Systems Engineering. Participating in MAGIC allowed cadets the opportunity to practically apply their classroom knowledge while serving as a member of a large multi-disciplinary team.

MAGIC Junior represents the year long work of the sixteen cadets, and we look forward to competing in the IGVC.

2.0 Design Process

The MAGIC team followed a five-phase design process which clarifies the task and organizes the development of the product. The five phases are: identify the needs, plan for the design, develop the engineering specifications, develop the concepts, and develop the product. Each phase uses specific tools to guide the design.

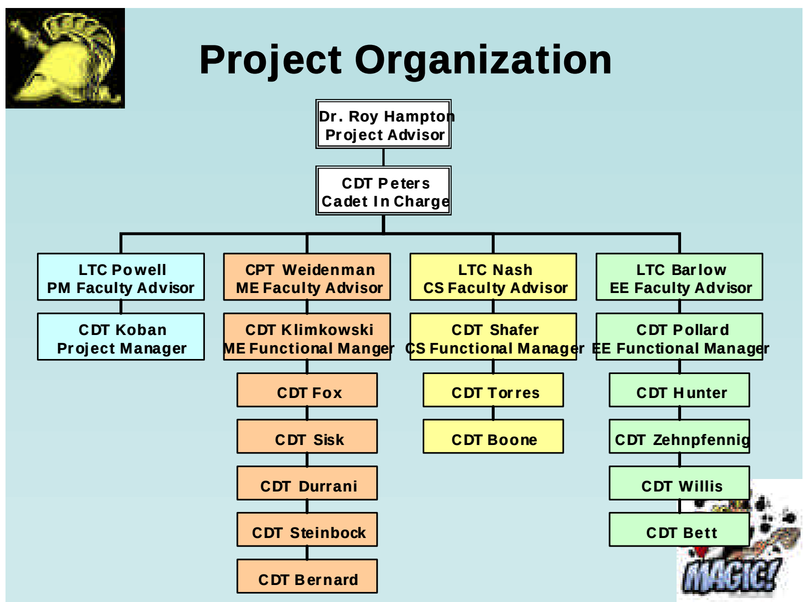

Figure 1: Project Organization

In the first phase, we clarified the problem. We used multiple mind-maps to appreciate the scope and depth of the project. Mind-maps illustrate interrelations, possible functions, and possible costumer requirements. We created one mind-map for the overall system and a mind-map for each subsystem. Next, we created an objectives tree to clarify the problem and develop a vision for the project. The objectives tree shows the hierarchy of objectives and constraints and leads to the functional decomposition which determines all the possible function the design needed to accomplish.

Planning for the design is the second phase of the design method. This phase is concerned with management: creating a work structure and managing time. First, we created a project organizational structure to assign personnel to areas of the project. Then we developed a Gantt chart to manage our time.

Development of engineering specifications is the third design phase. The outcome of this phase is the concrete engineering targets we will try to achieve with our design. We performed a pairwise comparison to assist in the development of a Quality Function Deployment (QFD) which develops engineering specifications. The QFD relates the customer requirements to tangible engineering design specifications. The QFD determines assigns each specification a weight. The weight of each specification is determined by the strength correlation it has to a customer requirement multiplied by the overall importance it has to that customer requirement. The QFD also benchmarks the competition, and for each specification, it assigns targets with a direction. The final out come of the QFD is the specifications list which is a ranked ordered list of engineering specifications.

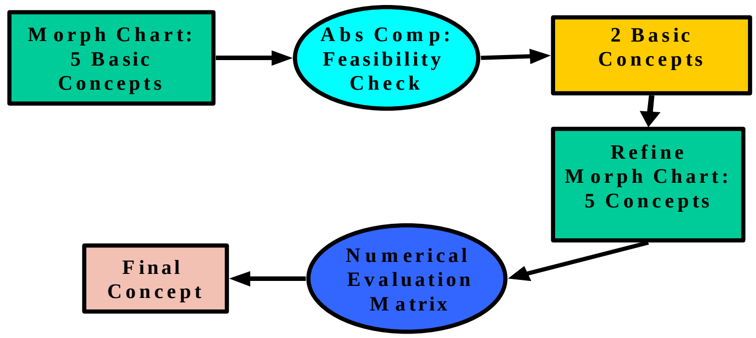

Figure 2: The Development of the Concepts

The fourth phase is the development of the concepts. There are two distinct tasks associated with the development of the concepts: generation of the concepts and evaluation of the concepts. In addition, this phase was iterative; we repeat and refine our process. Figure 2 outlines this iterative process.

During the concept generation phase, we brainstormed different forms to accomplish all the functions on the Functional Decomposition. Then, we organized each form to its respective function in a morphological chart. We generated five basic concepts by selecting various forms for each functions The goal of the first run was to push past stereotypical designs and evaluate both orthodox and unorthodox concepts. Next, we assessed the feasibility of each basic concept. We determined two basic concepts were realistic: a tracked-typed vehicle and a wheeled chart-like vehicle. The two concepts became the framework for the next iteration of the morphological chart. Here, we generated five focused concepts that utilized the best forms for the two basic concepts. Next, we assessed our five refined concepts

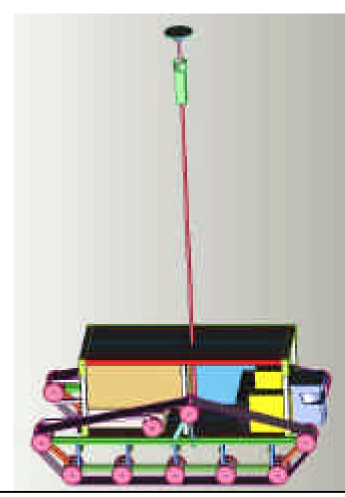

Figure 3: MAGIC Junior Final Concept

using a Numerical Evaluation Matrix. The NEM evaluates each concept's ability to accomplish the consumer requirements. The outcome of the NEM is our final concept, ending phase four.

The final portion of the five-phase design process is the development of the product. During this phase, the designers use a four step iterative process called form generation to design the components. The four steps are constraints, component configuration, connections, and component design.

With our final design complete in December 2003, we began construction.

3.0 Mechanical System

The Mechanical system is composed of several distinct components: the frame, the track, the vehicle shell, and the camera mount.

3.1 Vehicle Frame

The frame provides the vehicle with a skeleton. We determined the design objectives for the frame: easy to construct, durable, strong, and supports components. In addition, we wanted to minimize the volume as much as possible so the vehicle could maneuver around the course with less difficulty. A small frame lent itself to a "cage" concept. The caged frame would allow us to stack components if necessary.

Property	Value	Unit
Material type	Aluminum	
Frame length	3.00	Ft
Frame width	1.25	Ft
Frame height	1.25	Ft

Table 1: Frame Design Specifications

The main members are aluminum square tube; with a 1" cross-section and 1/8" thickness. An aluminum plate rests on the bottom of the frame to hold all the EE and CS components.

Bolt and nut connections hold the frame together. Each bolt, Grade 8 steel, connects two pressure plates which join the frame.

Figure 4: Corner View of Frame and Track

3.2 Track and Suspension

The suspension houses the track and holds the frame. It is made of 0.5 by .375 inch steel members. The suspension consists of two long rectangular cage connected by welded horizontal members.

Figure 5: View of Suspension

Figure 6: View of Suspension

The track was professionally made by the Thistle track company of Scotland. It is 82 inches long. The track has a coefficient of friction of 1.0 and has beveled corners to reduce the amount of force needed to turn the vehicle. Each track is driven by a cog wheel attached to a 0.143 hp electrical motor. The motor has an internal 1 to 30 gear reduction.

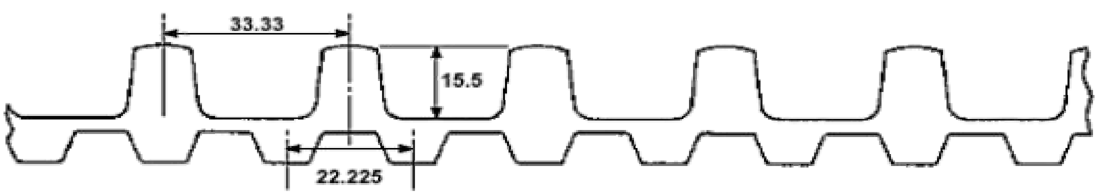

Figure 7: Cross-Sectional Area of Track (Dimensions are in mm)

3.3 Shell

The shell accomplishes several vital tasks. First, it protects the on board components from the outside projectiles. Second, it protects the electrical components from the environment. Finally, allows the user to view the internal workings of the machine.

The vehicle's shell is made of several panels of Lexan. Lexan is a clear plastic material which is nearly unbreakable. Each side of the vehicle has its own panel fastened by Velcro. This enables easy access to the components.

3.4 Camera Mount

The camera mount provides a stable, elevated platform to mount the camera and parabolic mirror, and it keeps the mirror within 72 inches of the ground. MAGIC Junior 2004 used an adjustable camera tripod glued to the top of frame. The glue used to mount the camera is a high quality epoxy, similar to epoxy glues used in aerospace applications, and it has a shear strength of 350 ksi.

4.0 Electrical System

4.1 Electrical Engineering Design

The Electrical Engineering team of MAGIC developed an electrical system that will supply safe, reliable power to all electronic components of the vehicle and provide the interfacing for all components with the laptop computer that controls the vehicle. The electrical system has three main subsystems: the motion control system, the power panel system, the remote control system.

4.2 Motion Control

Based on the overall design of the vehicle, the motion control system has to control both tracks independently. Additionally, the control system has to supply enough mechanical to ground power to maneuver the vehicle over varied surfaces, including an incline with a grade of 15%, and maintain a speed no greater than 5mph. The control system consists of: two Groschopp 24VDC, 2-pole motors, (Model #PM8014) with 1:30 gearboxes, a Galil motion controller and interconnect module, and two pulse-width modulated control amplifiers. The two motors act independently by using the computer to send instructions to the motion controller. The motion controller converts these instructions into a –10V to +10V signal that is sent to the amplifiers. The amplifiers then use this signal to determine how much current should be supplied to the two motors, in turn controlling the speed and torque output. Two shaft encoders provide a feedback signal to the motion controller to complete the closed loop circuit. This feedback allows the vehicle to determine how far is has moved and at what speed it is moving.

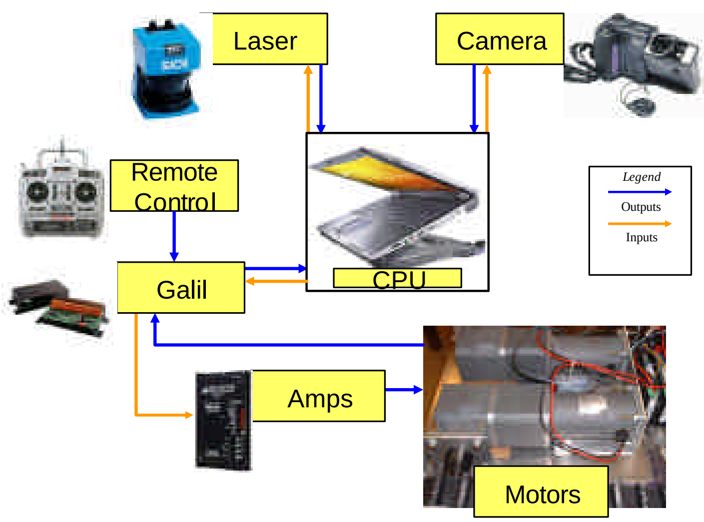

Figure 8: Electrical Block Diagram

4.3 Power Panel

The power panel system is the means of powering all the electrical components of the vehicle. It also houses the emergency stop system and the remote control system. The power panel consists of two DIN rails mounted on a u-shaped panel with a wired conduit running between the two rails. DIN components (such as the circuit breakers, fuse blocks, terminal blocks, and relays used in this vehicle) are made by manufacturers to be snapped on and off the rail.

This system is modular, modifiable, and simple to trouble shoot. Two 12V batteries provide power to all the components for one hour. The voltage from these two batteries is distributed into a 12Vand a 24V bus. The emergency stop system consists of a manual button and a remote switch. The remote switch is comprised of an RF transmitter that turns on or off a voltage that keeps a relay closed. When this relay is closed, it provides power to the motor amplifiers. The manual button is a switch that is connected in series with the remotely controlled switch. If either switch is opened, the power going to the amplifiers through the relay is cut off while the other components are not affected.

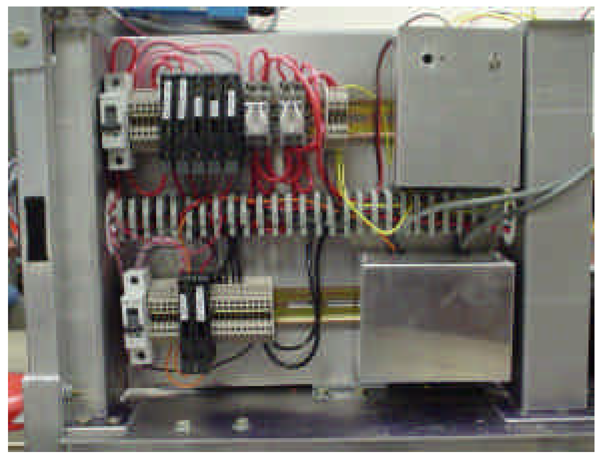

Figure 9: DIN Rail Power Panel

The emergency stop system meets the requirement of stopping within six feet upon activation and the remote stop works up to 110 feet away. There are two voltage regulator circuits mounted on the DIN rail. These circuits use LM350 IC chips to provide lower voltages to the camera and the laptop (12V and 24V respectively).

The power panel has several safety features including fuses to protect against current spikes and easy-connect battery cables which make it impossible to connect the batteries incorrectly and reversing the polarity. Additionally, the wiring meets the electrical standard code by being the correct gauge for the current running through them.

4.4 Remote Control

In order to move the vehicle from one location to another we have made a remote motion control using an RF transmitter. A circuit detects changes in the pulse widths emitted by the RF transmitter and interprets those signals to output different voltages. These output voltages go into the Galil motion controller. The Galil uses a small program stored in its RAM to interpret the changes in voltage as commands to go forward, backward, left, or right, which it subsequently executes.

5.0 Computer Science System

5.1 Software Design Process

In the development of the software system for MAGIC this year our team used a form of the Rapid Application Development (RAD) design process. The particular method we followed was a Parallel Prototyping Methodology which divides the project into distinct sub-projects that are designed in parallel in a repeated “Analysis, Design and Implement” cycle until the system is complete. This approach allowed the team to provide test systems in a rapid manner to the group for continuous testing throughout the project cycle.

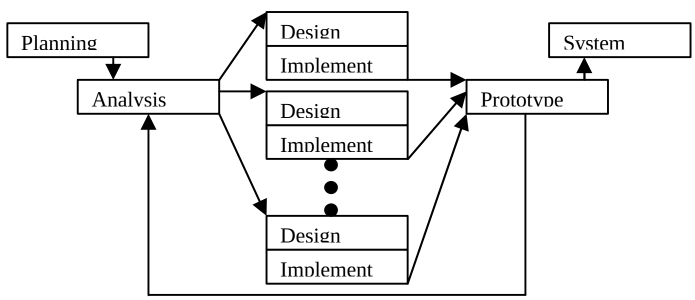

Figure 10: Software Design Process

5.2 Analysis

In this phase of the system development cycle we studied last year’s system to understand its strengths and weaknesses. We then identified opportunities for improvement and began to build a concept for the “to-be” system. Our team based this concept off of the requirements for the Autonomous Challenge rules. Analysis was collected in a Software Requirements Specification document (SRS) and submitted to the rest of the team as our software concept. The SRS detailed performance measures and standards to which our system design would conform

5.3 Design

Our design phase focused on how our system would meet the requirements developed in the Analysis phase. The project was broken into four logical sub-projects for parallel development. Our design of the system took large steps both to break away from the limited data model of the previous system and to create a system that would have as much information as possible to navigate the course. The design plan was captured in a Software Design Document (SDD), which clearly decomposes data and modules in the project and how they will meet the requirements of the SRS.

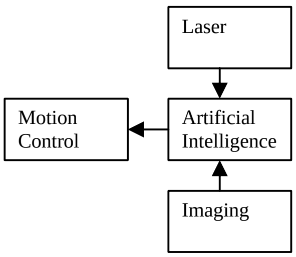

Figure 11: Computer Vision Diagram

5.4 Computer Vision (Boundary Avoidance) Implementation

Our team decided to continue using the previous catadioptric imaging system, using a mirror and camera system to overcome the shortcomings of the typical multi-camera "human eyes" approach to the vision problem. Using a RemoteReality "One Shot 360" parabolic mirror, our system acquires a top-down mirror image of the region surrounding the vehicle. We then apply a coordinate mapping to remove the mirror distortion and create a "bird's eye" perspective of the vehicle and an approximately 20'x30' region around it. Several passes of color threshold, edge detecting, and pixel chaining (line detecting) algorithms are then applied to detect the longest chains of pixels in the image, which are assumed to be course boundaries. The long range of our vision system ensures that our vehicle is always able to find the boundaries in an image, independent of line color or gaps in the lines.

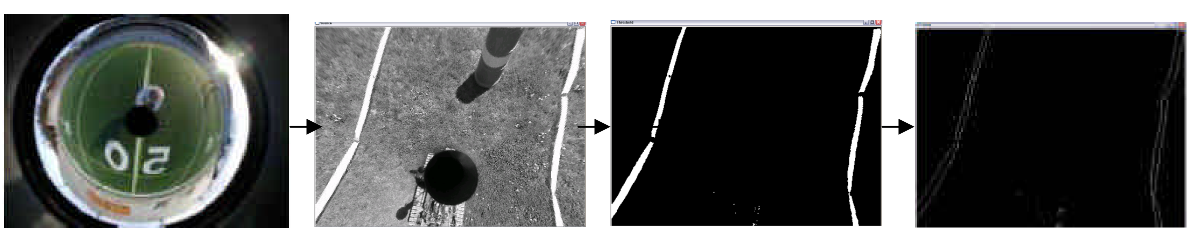

Figure 12: Image Processing

New this year is a software calibration and visualization package using OpenGL. This allows the user to calibrate the image on site, and to see the robots presentation as it does – showing the boundaries, barrels, current position, and path choice in a common coordinate system. This system has proven invaluable in the testing of the AI.

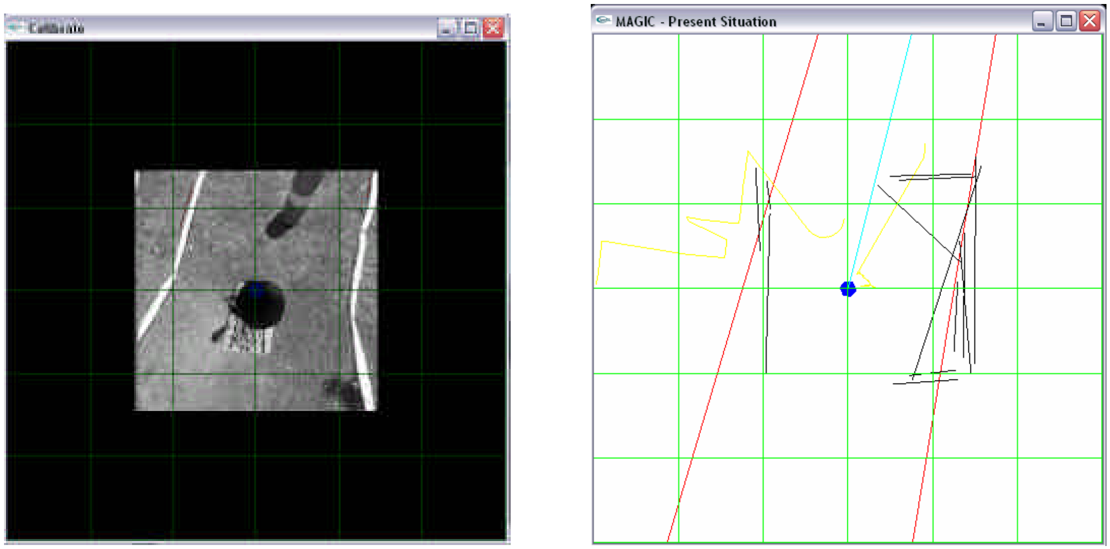

Figure 13: Open GL demonstration

5.5 Laser (Obstacle Avoidance)

Design on this module was centered around the SickOptic LMS-200 scanning laser. Our team decided to restrict the scanning range of the device to around 3 meters, as there is no need to scan further than our vision module can sense the course boundaries. The laser returns 180 degrees of measured distances. We decided to make the Laser Subsystem purely responsible for data collection, and allow the Artificial Intelligence to do all path decision making.

5.6 Artificial Intelligence (Path Planning)

The artificial intelligence subsystem uses the boundary data, in terms of coordinates of the boundary lines endpoints, and the laser data, in terms of distance to obstacle per degree scanned, to compute an optimal path. The general algorithm the laser uses is simply to check for gaps of *free space* – places where the robot can move forward and hit neither a boundary nor an obstacle. The algorithm chooses the largest gap and chooses a path and distance that will take it to the center of that gap.

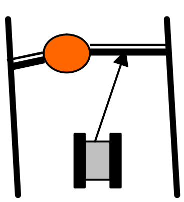

Figure 14: Path Selection

6.0 Concluding Remarks

6.1 Budget

The Department of Civil and Mechanical Engineering allocated $18,000 dollars for the construction of MAGIC Junior and transportation/lodging while at the IGVC. This $18,000 is split into $10,000 for travel and $8,000 for construction of the vehicle. Figure 15 shows the final expenses. The remaining funds will be used to purchase tools and equipment for next year's team.

Total Budget	$ 18,000.00
Travel Allotment	$ 10,000.00
Design Allotment	$ 8,000.00
Expenses	
Mechanical	$ 3,374.50
Electrical	$ 911.69
Computer Science	$ 1,143.97
Total Expenses	$ 5,430.16
Expenses	
Hotels	$ 1,862.00
Flights	$ 3,200.00
Car Rental	$ 240.00
Van Rental	$ 240.00
Total Expenses	$ 5,542.00
Remaining Budget	
Travel Allotment	$ 4,458.00
Design Allotment	$ 2,569.84

Figure 15: Budget

6.2 Testing

During late April and early May we completed construction and began testing. Testing then became a cycle consisting of four steps: 1) test, 2) identify deficiencies, 3) make improvements, and 4) test again. This cycle has continued up until our last day of classes.

Our test course generally consisted of tissue paper unwound to simulate the white lines with the use of actual traffic barrels as obstacles.

6.3 Acknowledgements

Crucial to the success of this project was the guidance and advice of the faculty advisors Major Wiedenman, Dr. Hampton, Lieutenant Colonel Nash, Lieutenant Colonel Powell, and Lieutenant Barlow. Additionally, the laboratory technicians provided valuable help in construction of the vehicle which required a high degree of skill.

6.3 Summary

MAGIC Junior represents the effort of sixteen undergraduate students from three different departments at West Point. Design began in the fall of 2003 and was complete by December 2003. Construction began in January 2004 and was completed by April 2004 with minor modifications being made until mid-May. While similar to past West Point entries, MAGIC Junior possesses many refinements such as smaller size and better tracks. We have high expectations for the competition.