Executive Summary

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Product Description

The proposed product is a hazardous material "seek and identify" vehicle that is autonomously controlled and electrically powered. The vehicle will use GPS navigation in order to locate a material container in an open field. It will then determine whether the material is hazardous and return to its starting position. Key features of the product include a durable body, a robust drive system, an onboard microprocessor, a GPS navigation system, hazardous material sensors, and an LCD screen/keypad user interface.

The vehicle body is constructed of high-density polyethylene (HDPE). The vehicle will operate in various conditions and on various surfaces. HDPE was chosen for the body material because its toughness and durability allow it to operate in these different conditions. HDPE also possesses a high degree of workability, which allows for easier construction and assembly. In addition, HDPE is lighter than materials of comparable strength and durability. This helps keep the vehicle as light as possible.

A robust drive system allows the vehicle to traverse the different surfaces and easily maneuver toward the target. It consists of two casters at the front and two pneumatic rubber wheels at the rear of the vehicle. The rear wheels are connected to two separate drive shafts, each of which is driven by an electric gear motor. Casters were selected for the front of the vehicle because they allow for a zero degree turning radius. Pneumatic rubber wheels were chosen for their traction and durability. The direct drive system was chosen for its simplicity of construction and operation.

The vehicle is autonomously operated by an onboard microprocessor. The microprocessor is easily programmable and allows the vehicle to operate autonomously based on predetermined performance requirements. In addition, the microprocessor integrates the various systems contained in the vehicle including the drive system, GPS navigation system, and hazardous material detection system

A GPS navigation system is included to allow the vehicle to autonomously navigate to a target location. The GPS communicates with the microprocessor, relaying the coordinates of the vehicle's location. The microprocessor can use these coordinates along with the coordinates of the target location to determine the straight path between the two points. The GPS system is important because it allows the vehicle to traverse a very large area in its search for hazardous material.

Two hazardous material sensors are included to allow the vehicle to determine whether there is hazardous material at the target location. The sensors are integrated with the vehicle through the microcontroller. The microcontroller deciphers the signals relayed by the hazardous material sensors to determine whether or not hazardous material has been found.

An LCD screen and keypad are included in the vehicle package to allow for the user to communicate with the onboard microprocessor. The keypad will allow the user to input simple commands and instructions into the vehicle. Commands input by the user include recording the vehicle's location, traversing the field, and searching an area for hazardous material. The LCD screen allows the vehicle to display information to the user such as menu options, coordinate locations, and most importantly, whether a given location contains a hazardous material.

Design Relevance

A hazardous material seek and identify vehicle has a very small and specific customer base which includes the military, law enforcement agencies, hazardous material clean-up contractors, and any type of organization that deals with hazardous waste or materials. The customer's qualitative requirements are that the vehicle be easy to operate, reliable, durable, fast, inexpensive, and low-maintenance.

There are currently no products on the market that can autonomously perform all of the tasks that this vehicle will be designed to perform. However, there are competitors that can accomplish similar goals in a different way. The main competition for this type of product would consist of remote control hazardous material "seek and identify" vehicles and hazardous material clean up crews. These remote control vehicles are operated by a human user and would be similar in size, weight, and weather capabilities to the proposed autonomous vehicle. The advantage of an autonomous vehicle over a remote controlled vehicle is that an autonomous vehicle is requires less user effort. A hazardous material clean up crew would need to be outfitted with suits that protect them from exposure to the hazardous material. They would also require gear to detect and identify the hazardous material. The advantage of an autonomous hazardous material "seek and identify" vehicle over a hazardous material clean up crew is that the vehicle prevents any risk of human exposure.

Design Process

The design process for creating the vehicle consisted of a few key steps. These included identifying design requirements, choosing and developing the design, creating final design specifications, and creating a prototype. A schedule of the design process is found in Appendix 1.

The first step was to identify design requirements. These design requirements were based on the vehicle's mandated capabilities and concept brainstorming. The description of the vehicle's necessary capabilities was provided by management. Brainstorming occurred first individually and then collaboratively. Topics included the vehicle's operation, modes of failure, and customer requirements.

A conceptual design was developed and chosen based on the established design requirements. The conceptual design was greatly influenced by information gathered from research on autonomous vehicles and small, electrically-powered all-terrain vehicles. Additional considerations for the conceptual design were provided through consultations with Dr. Steven Skaar and Mr. Greg Brownell. Dr. Skaar is professor at the University of Notre Dame who specializes in control of non-holonomic robots. He was consulted in order to help determine ways to implement control and identify the most practical drive system for the vehicle. Mr. Brownell is the manager of the ISALL laboratory at the University of Notre Dame. He was primarily consulted for information regarding vehicle navigation systems, electric motor selection, and circuit design. From this additional information and the design requirements, group members developed individual concepts for the vehicle's design. These concepts were discussed by the group as a whole in order to identify strengths and weaknesses. Along with the design requirements and the information gathered, the strengths and weaknesses of the individual concepts were used in determining a final conceptual design.

The next step was to complete the design by finalizing specifications. This portion of the design process included the construction of four generations of CAD model. Each subsequent generation was more specific and detailed than the previous generation. In addition, the majority of the engineering type work took place during this phase of the project. Engineering analysis utilized statics and dynamics in order to investigate the vehicle's size, shape, and power requirements. Engineering skills were also applied to the creation of electrical component schematics and a program to operate the vehicle.

The final step in the design process was creating a prototype of the design. The purpose of the prototype was to be a proof of concept of the final design. This part of the process involved purchasing components, creating parts through the use of ProEngineer and a CNC machine, assembling a prototype, and programming the prototype. Resources were allocated for purchasing based on need and importance with the drive system receiving the highest percentage of funding. A bill of materials that includes the cost and sources associated with each item on the list can be found in Appendix 2.

The schedule for the design process was based off the schedule of primary milestones assigned by management. The schedule was broken up based on the key steps previously mentioned with the goal of allowing enough time to correct show stoppers. Key decision points included determining a design, finalizing the design, completing construction of the prototype, and integrating electrical systems. The complete schedule can be found in Appendix 1.

Options Considered

There were three competing concepts that were considered for the vehicle's design. The three concepts were very similar to each other. They consisted of rectangular bodies constructed out of HDPE, contained similar electrical components, and searched for hazardous material in similar fashions. The most significant difference between the three concepts was the drive system. The drive system for Option 1 consisted of four pneumatic wheels that were directly driven by four separate motors. Option 2 proposed using a motor on each side of the vehicle to drive two pneumatic wheels using a chain and sprocket system. Option 3 used a motor on each side of the vehicle to directly drive a pneumatic wheel located in the rear of the vehicle and to rely on two casters to support the vehicle's front end. Below, Table 1 compares the three different options while Figures 1-3 contain sketches of each of the options.

Option	**Key Features**	**Technical Challenges**
Option 1	• Four pneumatic wheels directly driven by four independent motors • Large torque output per wheel • Fast	• Accounting for large possibility of slip • Minimizing weight • Assuring that there is enough power for all four motors
Option 2	• Four driven wheels • Chain and sprocket drive system similar to tank drive system • Zero degree turn radius	• Accounting for large possibility of slip • Creating efficient power transfer in chain and sprocket drive system
Option 3	• Two directly driven rear wheels • Two casters supporting front of vehicle • Zero degree turn radius • Minimal slip	• Accounting for caster drag when reversing directions • Assuring that two driven wheels provided enough power to drive

Table 1: The Three Main Options Considered

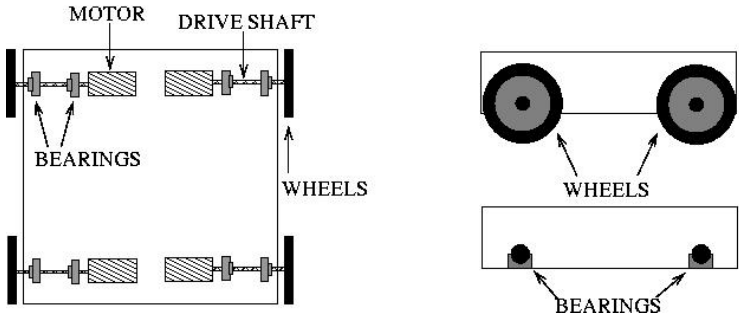

Figure 1: Option 1

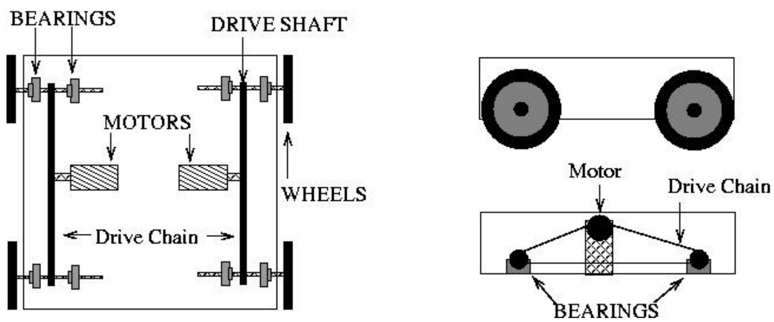

Figure 2: Option 2

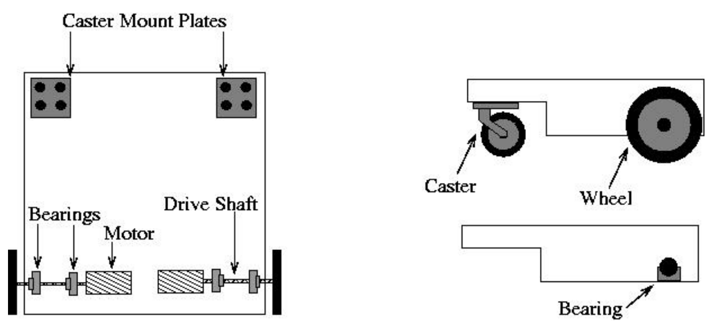

Figure 3: Option 3

Solutions Selected

The most critical aspect of the proposed vehicle was the effective integration of GPS technology. There were three key components that needed to be designed and fabricated in order to properly test the GPS technology's feasibility.

The drive system was the first key component for which the group selected a solution. The group decided that Option 3 (described above; front casters and rear driven wheels) would result in the most successful and reliable drive system. It was recommended by Dr. Skaar and Dr. Michael Stanisic, a member of the project management team. The key advantage identified in this design was the possibility of zero wheel slip during turning and maneuvering. A further advantage of Option 3 was the simplicity of the design and the low level of difficulty associated with construction. In addition, the two technical challenges associated with Option 3 could be overcome with proper motor selection.

The next key component addressed by the group was the body design. The body needed to be designed to effectively implement the drive system. It needed to be as light as possible to allow for the motors to operate as efficiently as possible. A design was created by the group that allowed for casters to be mounted on the base at the front of the vehicle, and driven pneumatic wheels to be mounted at the rear of the vehicle. It was also determined that the body would be constructed out of HDPE, a material that has an exceptional strength to weight ratio. The HDPE was to be connected and supported by steel L-brackets fastened using machine screws. Appendix 3 contains drawings of the body's design.

The electrical system of the vehicle was the final key component addressed by the group. The electrical system is the most critical component of the vehicle because it integrates and controls the drive system, the infrared detection sensors, and the GPS navigation system. As mentioned above, a microprocessor provided by management is used to control the electrical system. The electrical system is subdivided into hardware and software which work together to control the electrical aspects of the vehicle. Appendix 4 contains a flow chart of the pseudocode for the control logic.

Formal trade studies were conducted by the group members and played a key role in decision making for each of the three key systems mentioned. For the drive systems, two of the formal trade studies helped to determine the output requirements of the vehicles electric motors. The minimum torque required by the vehicle was determined to be 0.9 N-m. The maximum torque that could be achieved without wheel slip was determined to be 2.0 N-m. Another formal trade study was used determine the proper height and width of a mast and boom system on which the infrared detection sensors would be mounted. From this trade study, it was concluded that to maximize the capabilities of the infrared sensors, they should be mounted at a height of 30 in. above the ground and 18 in. apart. The final two formal trade studies helped determine the proper logic for searching for hazardous material. One of the studies examined GPS resolution and how to effectively use GPS feedback to move to a target location. The other study determined the best pattern for searching once a target location had been reached. This trade study concluded that a spiral square search pattern would be the most effective way to search the targeted area. In addition, informal trade studies were conducted to dimension components of the drive system as well as determine the proper design of the vehicle's electrical circuits.

This solution appeared to be the best fit for meeting the design requirements. The anticipated strengths of this design include a zero degree turn radius, simplicity of the infrared detection system, and an easy to implement drive system. The design was created with the overarching guideline of simplicity. The anticipated weaknesses of this design are the instability of the casters at high speed, forces resulting from caster drag during reversal of direction, small search area, and limited torque output by the motor. Despite these weaknesses, the strengths of this design, specifically the simplicity, lead the group to believe that it has the potential to be a very successful option

Implementation Details and Feasibility

In the development of the proof-of-concept prototype, several key issues arose that would influence the proposed design. The design team was able to prove feasibility of the concept, and with modifications to the design, could prove that this product would be competitive with other technologies.

During the development and testing of the prototype, it became clear that motor selection is essential to an effective drive system. Motors should be sized generously so they do not operate near their stall torque. This is due to the fact that operating at stall torque increases the possibility of mechanical failures like stripped gears.

The prototype showed that a small vehicle can be guided through the use of GPS technology to within approximately 10 feet of a target. GPS is accurate but not repeatable, which necessitates a refined search algorithm in addition to the traversing mode. Being able to make precise turns is essential to all aspects of searching. The implementation of an electronic compass would allow for this. Calibration of the differential rear steering was not accurate enough to determine orientation, so more complicated search patterns were needed.

Development of the body and drive system of the vehicle proved successful. Most difficulties arose with the electronics and software. In development of the code, the design team realized how important a robust code is. The next generation of this vehicle would include more advanced embedded intelligence that would allow for simple debugging, calibration, and modification.

In the development of the vehicle, the value of effective mechanical design became evident. Shouldering the body panels for assembly was beneficial. In addition, a shouldered driveshaft supported by bearings proved beneficial due to the fact that it could support thrust loads. The design team realized that having a reliable and robust mechanical drive system allowed more focus to be placed on the important aspects of the vehicle, the electronics, software, and systems integration.

Conclusion

The final proposed version of the hazardous material seek and identify vehicle would be very similar to the initially proposed design in a physical sense. The body would be constructed of HDPE and the sensors would be mounted on a stationary boom. The HDPE is durable and easy to work with, while stationary sensors limit the amount of parts and the number of problems that could be encountered. A robust drive system would be created using two rear driven wheels and two free-moving casters to support the front of the vehicle. This drive system is simple to implement, minimizes the parts, reduces slip, has a zero degree turning radius, and would be easy to control. The final version of the vehicle would also be autonomous and electric. It would use GPS technology for navigation, but would incorporate an electronic compass to create a more accurate and effective reckoning system. Bumpers with touch sensors must be incorporated in order to help the vehicle effectively maneuver around objects.

An autonomous hazardous material seek and identify vehicle is feasible. A robust drive system can be designed and implemented, a GPS navigation system can be utilized, and a physical platform can be developed to meet the purposes of the project. The big hurdle for further advancement will be the development of an autonomous code that can successfully control the vehicle in locating a material container in an open field, determining whether the material is hazardous, and returning to its starting position while avoiding obstacles in the process.

APPENDIX 1: Schedule

DATE	ASSIGNMENT/GOAL	COMPLETION
January 22	Finalize Design Requirements	Yes
January 24	Individual Concept Memos with Sketches	Yes
February 7	Finalize Design Concept	Yes
February 12	Preliminary Concept Memo; Trade Study Proposals	Yes
February 19	Complete Interface with Infrared Sensors, LCD, and Key Pad	Yes
February 28	Individual Trade Studies	Yes
March 13	Completion of Design for Drive System	Yes
March 18	Prototype Performance Requirements	Yes
March 20	Logic Flow Chart Pseudocode Complete	Yes
March 25	Construction Complete on Prototype Body	No (Completed on 4/8)
March 27	Complete Interface with Motors	Yes
April 1	Complete Fabrication and Assembly of Drive System	Yes
April 3	Prototype Fully Assembled; Virtual Prototype Completed	No (Completed on 4/8)
April 8	Concept Design Documentation Draft; Hard Circuitry Completed	Yes
April 15	Prototype Complete	
April 22	Concept Design Review Presentation	
April 24	Concept Design Review Presentation	
April 29	Final Concept Design Documentation Complete	

APPENDIX 2: Bill of Materials

Part	Quantity	Total Cost	Source
DC Electric Gear Motor	2	$107.68	The Robot Marketplace
Aluminum Drive Shaft	2	N/A	AME Machine Shop
Aluminum Shaft/Motor Coupler	2	N/A	AME Machine Shop
Aluminum Shaft/Wheel Hub	2	N/A	AME Machine Shop
10-24, 1/4" Length Set Screw	8	N/A	AME Machine Shop
M10 Thread, 50 mm Length, 1.50 Pitch Machine Screw	2	N/A	AME Machine Shop
Nylon-Insert Locknut M10 Screw Size, 1.5 mm Pitch	2	N/A	AME Machine Shop
Pillow Block Ball Bearings for 1/2" Diameter Shaft	4	$48.30	McMaster-Carr Supply Co.
M3x25mm Machine Screws:	100	$2.84	McMaster-Carr Supply Co.
8" x 1.25" Tire with 5-Spoked Wheel	2	$29.98	Northern Tool and Equipment
6" Pneumatic Swivel Caster	2	$17.98	Northern Tool and Equipment
4' x 4' x .375" HDPE Sheet	1	$69.10	MSC Industrial Supply
Base: 19.75 x 10.50 x .375		--	
Overhang Base: 19.75 x 8.375 x.375		--	
Right Side Panel: 18.125 x 8.875 x .375		--	
Left Side Panel: 18.125 x 8.875 x .375		--	
Back Panel: 19.75 x 8.875 x .375		--	
Front Top Panel: 19 x 3.75 x .375		--	
Front Bottom Panel: 19 x 20 x .375		--	
Packaged GPS Chip	1	--	Provided by Management
Infrared Sensors	2	--	Provided by Management
Microprocessor	1	--	Provided by Management
LCD	1	--	Provided by Management
Keypad	1	--	Provided by Management
2" x 5/8" Steel L-Brackets	48	$30.00	Lowes Hardware
1/4-20 x 0.75" Machine Screws	50	$4.81	Lowes Hardware
PVC Piping	N/A	$7.90	Lowes Hardware
PVC Flange	1	$11.00	Lowes Hardware
Wiring	N/A	--	ISALL
N-Type Transistors	2	$20.00	ISALL
1/4 - 20x1.5" Machine Screws	24	$5.88	Home Depot
1/4 - 20x0.75" Machine Screws	25	$4.90	Home Depot

APPENDIX 3: Body Design

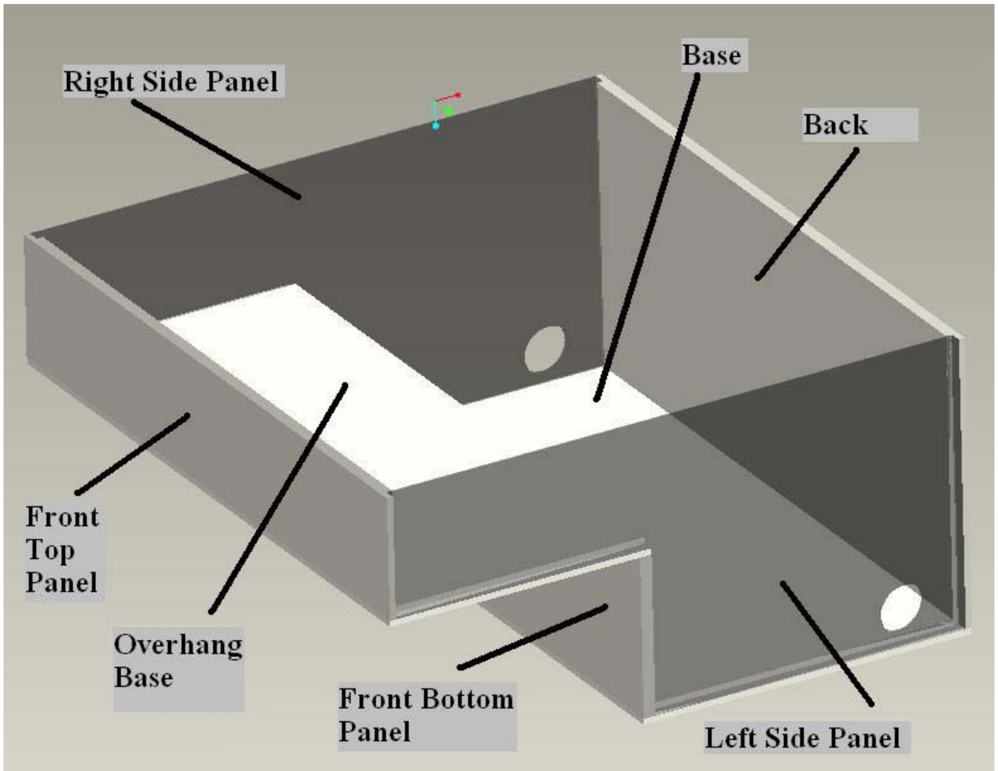

Figure 4: Body Assembly

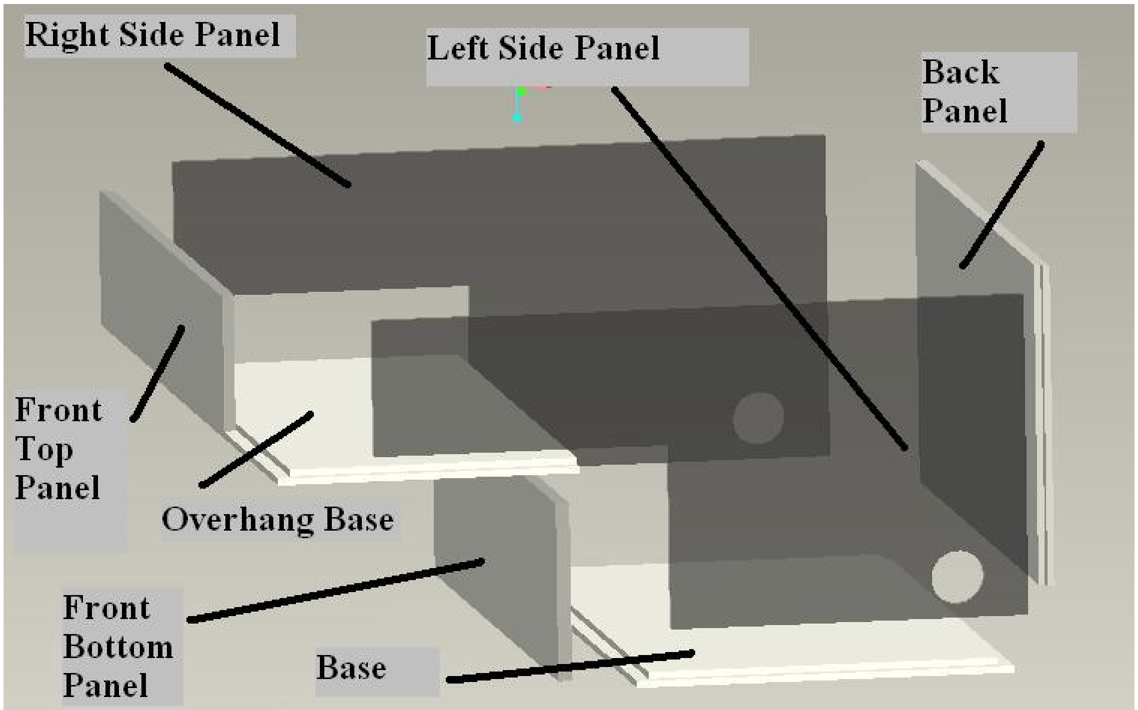

Figure 5: Body Assembly Exploded View

APPENDIX 4: Flow Chart of the Pseudo Code