AMERICAN UNIVERSITY OF SHARJAH

COLLEGE OF ENGINEERING - MECHATRONICS ENGINEERING DEPARTMENT

SHARJAH, UNITED ARAB EMIRATES

ADAM DESIGN REPORT 2011

TEAM SUPERVISOR

Dr. Mohammed A. Jarrah

TEAM MEMBERS

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Naveed Abbasi	Kamal Saadeddin	Md Sheruzzaman Chowodury
	Muhammad Zulkifli	

I, Dr. Mohammed A. Jarrah, Professor in the American University of Sharjah in Mechatronics Engineering, hereby certify that the design and engineering of the vehicle by the current student team has been significant and equivalent to what might be awarded credit in a senior design course.

Signature	Date
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1. Introduction

This report brings to you the Autonomous Vehicle which is named ADAM. ADAM was developed by students from the Department of Mechatronics in the American University of Sharjah in Sharjah, UAE. ADAM is a vehicle that has the capability of detecting obstacles, avoiding them, and staying within a track that is identified by two dashed or straight white lines. Also, ADAM is able to navigate its way to pass by several checkpoints while avoiding any obstacle that might be present in its environment and getting back to its base (i.e. initial position). Because of all that, ADAM could be widely used in different applications including but not restricted to: military applications, rescue missions, and autonomous vehicles. In hazard, unknown, and/or dangerous areas where it is unsafe to use human beings, ADAM can serve as a substitute to ensure not having any human casualties.

ADAM has these abilities because of a complete integration of Mechanical, Electrical, and Software designs. Mechanically, ADAM is a differential drive system that is powered by two motors connected to two wheels through which speed and steering control could be achieved with a free wheel for balancing the system. Electronically, ADAM has several sensors through which it can perceive its environment as well as having driving circuits to power both motors. Considering software, the software is the main part of ADAM. It is considered to be the brain of ADAM that makes all the decisions and in which all activities are decided.

This document will take you through the steps of designing and implementing ADAM Vehicle in order to achieve the objectives of Autonomous and Navigation Challenges of the IGVC. This document includes an overall description of the various aspects, features, and functionalities of ADAM.

2. DESIGN

2.1. TEAM STRUCTURE

The designing of ADAM started on February 2011 which is considered to be too late compared with other groups who have most likely started working earlier than that. Therefore, it was imperative to work efficiently. This means dividing the team into groups to finish several tasks in parallel. We have identified three main groups in the design process as specified in Figure 1.

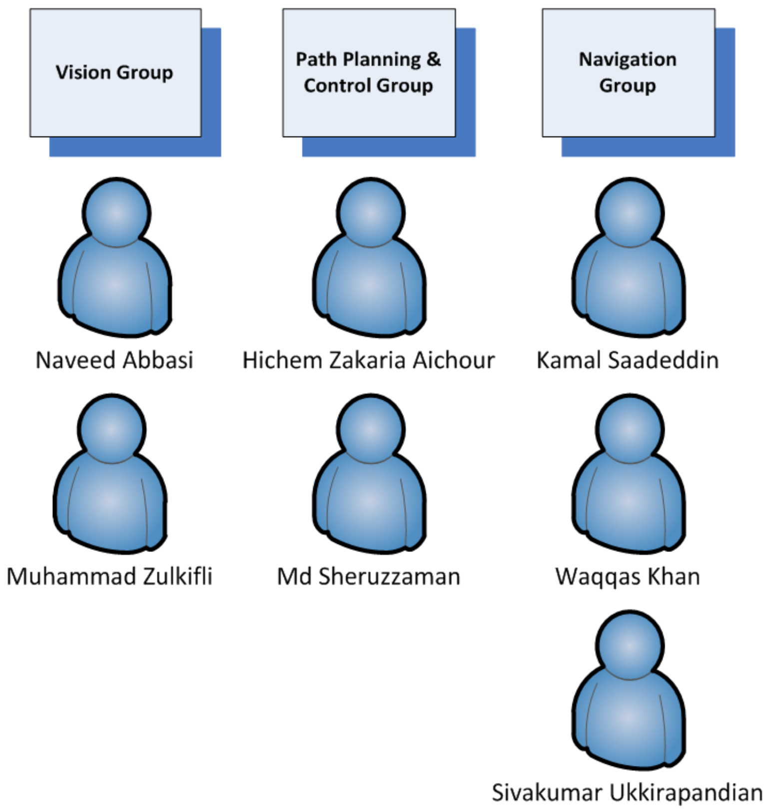


Figure 1: Team Architecture

With such a division of groups, each group was able to fulfill its task assuming that the required data from the other group is given to it. Afterward, when each group is done with its part, the integration is performed between the various tasks completed by the three groups which would produce the design system. Based on this description, we are using top-down design and bottom-up implementation scheme.

2.2. OVERALL ARCHITECTURE

Based on the above division of groups, we have decided to build the overall architecture to be as shown in Figure 2.

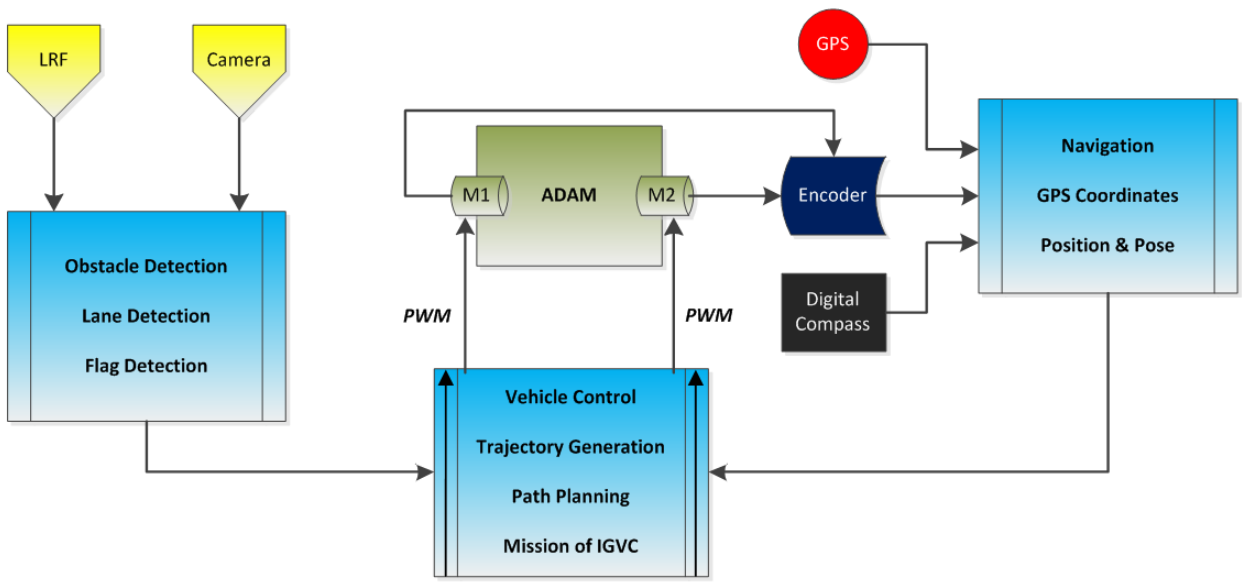


Figure 2: Overall Architecture

2.3. HARDWARE DESIGN

ADAM is a differential drive system that has two motors and integrated with different sensors that have the role of perceiving the environment around the vehicle. It has one main brain compromised of a laptop that takes all the data and processes them to control ADAM. Also, it has several dedicated microcontrollers that have different roles.

2.3.1. Hardware Architecture

ADAM has the following Hardware Architecture.

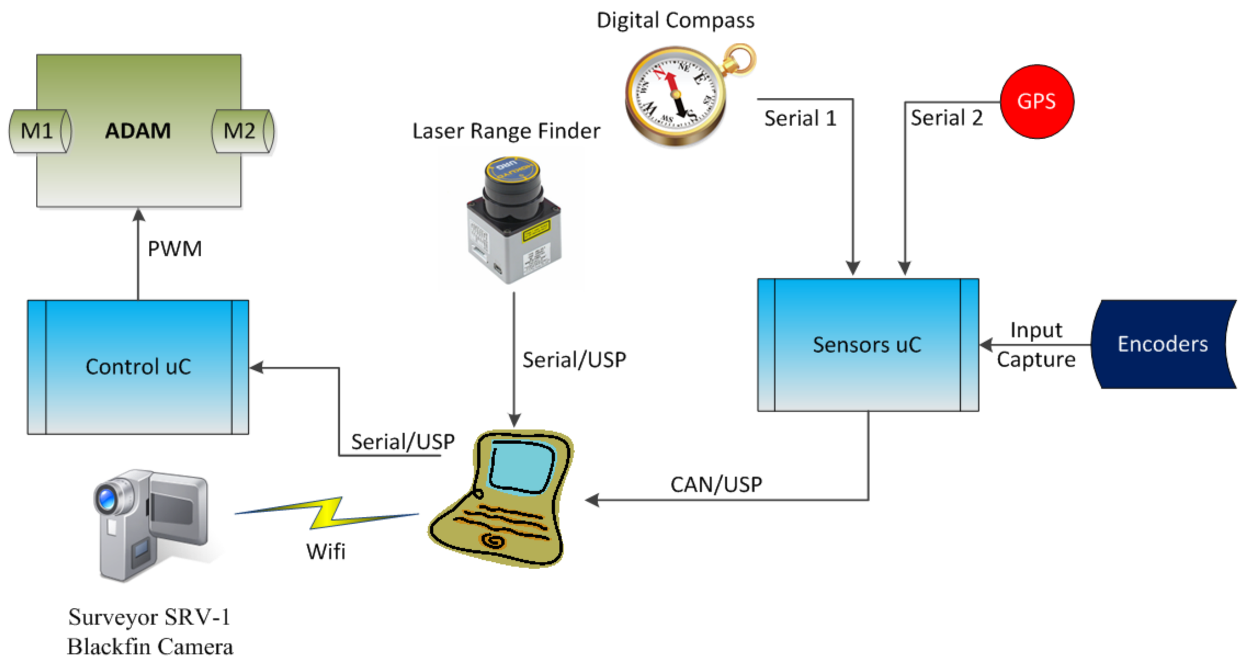


Figure 3: Hardware Architecture

As shown in Figure 3, first of all, GPS, Digital Compass, and Encoders data will be received and processed with a dedicated microcontroller that has the role of obtaining all the readings of these sensors, processing those readings, and organizing them in a package that would be sent to a laptop through a CAN/USP converter. The laptop will receive the position and orientation of ADAM from the Sensors Microcontroller, the obstacle position from the Laser Range Finder, and the flag and lane position from the camera. Using these data, it will use a path planning and obstacle avoidance algorithm. Based on those algorithms, the laptop will send control data to another microcontroller that is dedicated for control purpose where control action would take place and ADAM will move based on the generated PWM signals.

2.3.2. Chassis

The chassis of ADAM consists of two wheels that are connected to two DC motors with a third free wheel and a board of aluminum where all the components are placed. Figure 4 shows the different components of the chassis of ADAM.

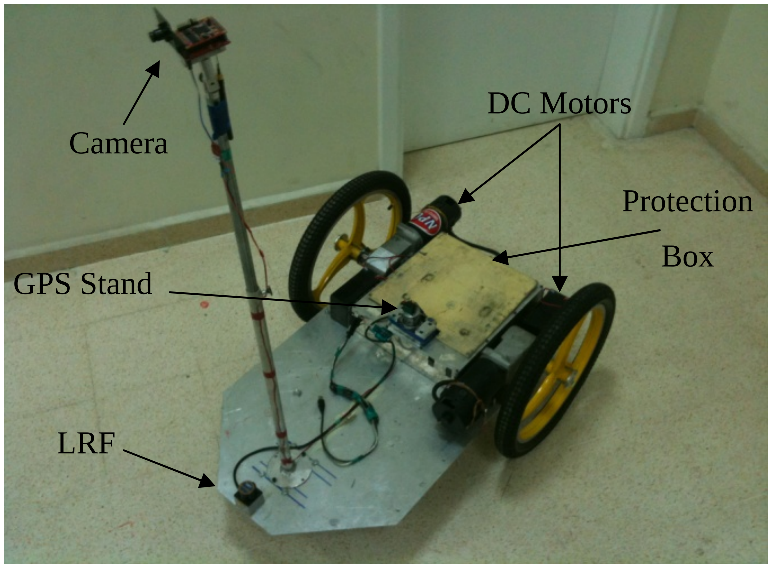


Figure 4: ADAM

For protection purposes, microcontrollers and digital compass have been placed in a protection box to protect them from light rains that might be present in the contest. A protection for the camera and the LRF is added as well.

2.4. ELECTRICAL DESIGN

2.4.1. Sensors

In order to perceive the environment around ADAM, several sensors were used. Each sensor has a specific purpose as shown in Table 1.

Table 1: Sensors

#	Sensor	Purpose
1	GPS	Positioning (Longitude and the Latitude)
2	Digital Compass	Orientation (Yaw, Roll, & Pitch)
3	Encoders	Speed and Orientation (Dead-Reckoning through Forward Kinematics)
4	Laser Range Finder	Obstacle Detection
5	Camera	- Flag Detection - Lane Detection - Obstacle Detection

2.4.1.1. GPS

The GPS system used in Adam's is the NovAtel SUPERSTAR II GPS system as shown in the in the figure below.

Technical Specifications/Features:

- It can provide position accuracy of 1.5 meters CEP (Circular Error Probable) without a correction signal.
- The system uses Omnistar HP differential corrections to achieve an accuracy of .10 meters CEP.
- It can be powered by +7 to +15 VDC and it consumes 3.7W of power.
- CDGPS and WAAS corrections can also be acquired to improve accuracy.
- It is shock, water proof and dust resistant.

This GPS system will be used in the navigation challenge to get the position of the vehicle and guide it towards the waypoints.

2.4.1.2. Laser Range Finder

The obstacle detection system used by ADAM is a HOKUYO URG-04LX Laser range finder. It can scan up to 240 degrees with maximum detection range is 4 meters. The LRF is interfaced through serial connection to the main computer.

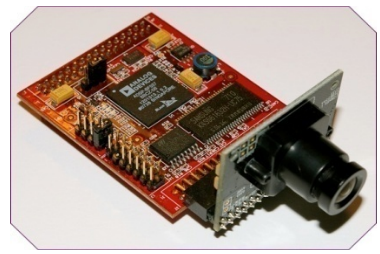
Technical Specifications/Features:

- 5 Vdc ±5%
- 500 mA (Rush Current 800 mA)
- Detect from 20mm → 4000mm
- Accuracy of ±10mm for 20mm → 1000mm
- Accuracy of ±1% for 1000mm → 4000mm
- 1 mm resolution
- 240^0 Scan Angle
- 0.36^0 angular resolution
- 100 ms/scan

2.4.1.3. Camera

The vision system used by ADAM utilizes a Surveyor SRV-1 Blackfin Camera. The main objective of using the camera is to detect the position of white lines and obstacles in the path. At the same time, the camera is used to recognize green and red flags and their position in the track. This information is then used by another program which makes decision for ADAM in which direction to move.

Technical Specifications/Features:



- WiFi communication via Lantronix Matchport WLAN802.11g radio
- 1.3M pixel, 3.6mm f2.0 standard lens
- 90 degrees FOV
- 7.2 Vdc supply
- Powered by a 500MHz Blackfin BF537 Processor

2.4.1.4. Encoder

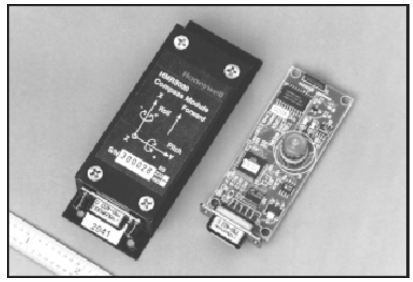
Two Vishay Model 120e encoders were mounted on two motors and were used to read the wheels' angular displacement and velocity of the vehicle to implement dead reckoning.

Technical Specifications/Features:

- It is a light-duty optical encoder.
- Expected life: 10 million revolutions
- Resolution: 128 pulses in a quadrature.
- Stainless steel shafts.
- Operating temperature: - 40 °C to + 65 °C.

2.4.1.5. Digital Compass

A Honeywell's HMR3000 digital compass is used to measure the magnetic heading angle, pitch and roll values of the vehicle.



Technical Specifications/Features:

- It is a solid state magneto-resistive sensor.
- The compass provides response time up to 20 Hertz
- It provides heading accuracy of 0.5° with 0.1° resolution.
- Heading angle can range from 0° to 360°.
- Its pitch and roll angles ranges from -45° to 45°.

2.4.2. Power Supply

For power supply, ADAM uses six 7.2 V, 3000mAh Ni-Cd batteries. Four of the six batteries are used by the two motors. Each motor is connected to a voltage regulator or 12 V that is connected to two Ni-Cd batteries that are connected in series. All the other sensors as well as the microcontrollers are connected to the two other batteries through other voltage regulators.

2.4.3. E-Stop

ADAM is supported by two E-Stop buttons. One of them is a mechanical switch and is located in the rear end of ADAM around two feet from the ground. The other E-Stop is a power switch that is controlled by a remote control. Whenever the remote control is pressed, a signal will be sent to the power switch to toggle its state. Both switches (Mechanical and Power Switch) connect the power to the motor circuit; therefore, whenever any of them is off, ADAM will go to a complete stop state.

2.4.4. Lamp

For safety purposes, ADAM is supported with a lamp that has a solid light when the power is turned ON. The light starts flashing whenever ADAM is running in autonomous mode.

2.5. SOFTWARE DESIGN

2.5.1. Lane Detection

For Lane Detection, Surveyor SRV-1 Blackfin Camera is used with an image processing software called Roborealm which consists of many image processing modules. Each module has a specific task and by selecting the appropriate modules and functions, the software is able to carry out the desired task.

Line detection is performed by applying Hough transform on several filtered images. These filters serve the purpose of filtering noise and any other objects which does not represent white lines. The image captured by the camera is first normalized and then adaptive threshold used to keep only that part of image which would represent white lines. And then after dilating the image, Hough transform is used for creating lines based on points. Figure 5 shows how lane detection is carried out using image processing.

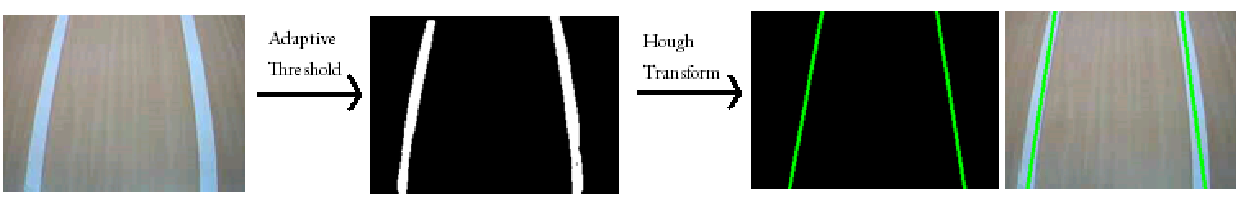


Figure 5: Lane Detection

2.5.2. Obstacle Detection

The obstacle detection is implemented by processing the results of each scanning process coming from the laser range finder. Laser will detects every object that lies on the scanning field of view and information of range, bearing, & timestamp relative to the sensor sends to the computer. By transformation of coordinates from polar to Cartesian of this relative positions, a 2-D the obstacle map can be generated.

Each points that generated on the map is corresponded to a shell of an active grid that used by path planning. This grid is always moving with the vehicle and located at the center of the grid. This grid has fixed length and width. Thus, the map of obstacle only stored temporary.

However, for navigation challenge, a global obstacle map is needed. In order to accomplish this task, a sensor fusion program is developed. By combining the information readings from GPS, compass, odometer (encoders) and LRF a global map can be generated. The reading from GPS, compass, and odometer is bundled into a packet which contains information of global X ,Y position and heading angle of the vehicle. Then the obstacle relative position that obtained from the laser is transformed to global position by utilizing the vehicle position.

As a backup, Surveyor SRV-1 Blackfin Camera is used as well for obstacle detection. Obstacle Avoidance is performed by using edge detection technique and floor finder technique. For the edge detection technique, canny module is used which is an edge detector and then the resulting image is processed through several filters to smoothen the image and identify the highest point in the structure which represents the most distant goal that ADAM could head towards without hitting an obstacle. Based on the X location of this point with respect to the center of the screen we would then decide if ADAM should move left, straight, or right to reach that goal point. The floor finder technique is also implemented to make sure the vision system does not confuse the floor as an obstacle and performs the desired tasks. Figure 6 shows how the camera would detect obstacles.

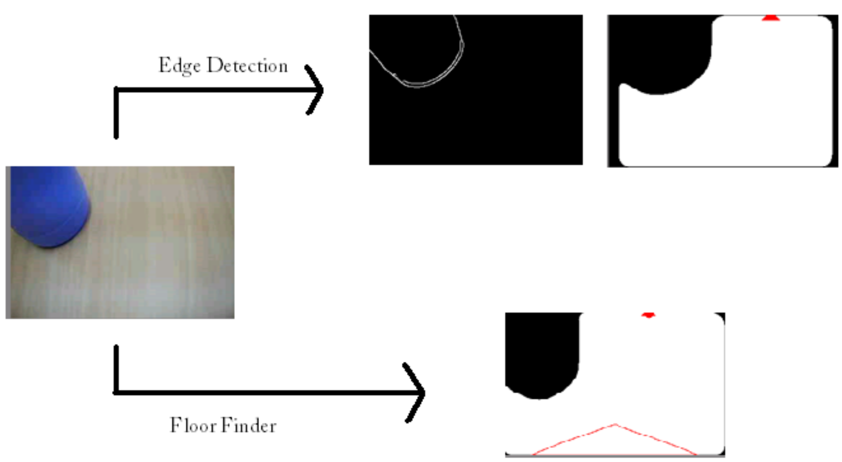


Figure 6: Obstacle Detection

2.5.3. Flag Detection

The vision system is also responsible for tracking red and green flags placed along the track and determine their location. This is done using Surveyor SRV-1 Blackfin Camera. Color of the flags is recognized using the image recognition module and the corresponding position is computed so as to direct ADAM to the proper direction.

2.5.4. Vehicle Positioning and Orientation

The position of the vehicle at any point of time is estimated from sensors using Kalman filtering. The GPS device gathers the information in the form of longitude and latitude. The digital compass collects the attitude of the robot in the terms of yaw, pitch and roll. The wheel encoders return the relative displacement of each wheel.

The Kalman filter estimated position is then used to navigate around the field, reach waypoints and identify obstacles and lines. The error analysis for Kalman filtered sensor data is done in Matlab. The vehicle waypoint testing for navigation was done separately before system integration.

2.5.5. Path Planning & Obstacle Avoidance

Path planning is accomplished on ADAM in two levels. The global path planning is done by D* Lite algorithm [1] and the local path planning is done by Vector Field Histogram plus (VFH+) algorithm. D* Lite algorithm examines the obstacle map created by the Vision group and plans an optimized path between the start position and the goal position. The advantage of this algorithm is that, unlike A* search algorithm, D* Lite algorithm can dynamically re-plan the path as the map is updated with new information.

Once D* Lite finds the optimal path, it generates an intermediate waypoint every 2m and sends it to the local path planner. The local path planner, VFH+, uses the obstacle map created by the LADAR and generates a polar histogram that represents the environment of the robot. Taking that into account and taking the dynamics of the vehicle into account, the VFH+ calculates an appropriate steering command that steers the vehicle to the next virtual waypoint.

While both D* Lite and VFH+ can create a path to the goal, they will not necessarily create an optimal path. D* Lite offers global optimality of the path but cannot avoid obstacles in real time, where as VFH+ can only offer local path optimality but not global. That is why it was decided to integrate the two and have the best of both algorithms.

In order to understand and debug any potential error, the D* Lite and VFH+ algorithms were first simulated using MATLAB. In the simulation, the user is able to input the obstacle location in a 10x10 grid and the algorithm determines the optimal path using the D* Lite algorithm.

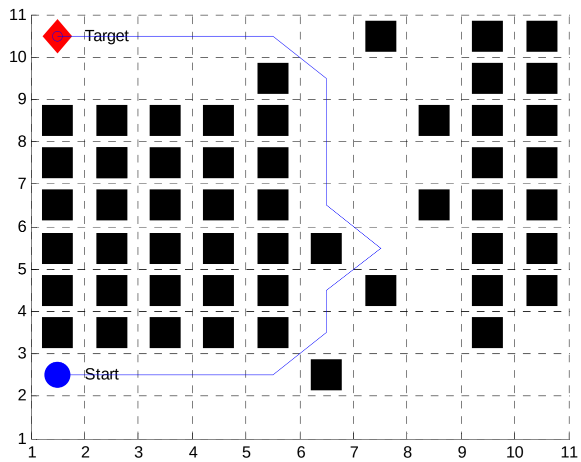


Figure 7: Simulation of D* Lite Algorithm

D* Lite is an incremental heuristic path finding algorithm that is very similar in idea to the popular A* search algorithm. D* Lite was proposed by Sven Koenig and Maxim Likhachev in [1]. It works by dynamically calculating the cost function of each node and selecting to move to the node with the least cost.

VFH+ works in three steps. The first step uses the distance, angle and time information from the LADAR sensor and generates a 2-D Cartesian grid, called active grid because it always has the vehicle in the center with the grid always moving with it. The second step uses this active grid to map a polar histogram that represents the vehicles obstacle environment. The polar histogram has peaks, which represent an obstacle, and valleys, which represents passable space. In the third step, the valleys are compared with a threshold value, and classed as wide or narrow. The wide valleys are then selected as potential candidates and the vehicle then travels through the one that is relatively closer to the next intermediate waypoint [2].

3. Design Consideration

3.1. Safety

While building ADAM, safety was a main consideration. First of all, the chassis of ADAM was built so that it doesn't have any sharp edges. As well, the speed of ADAM doesn't exceed 6 mph so that it doesn't harm anybody if it happens to collide.

3.2. Modularity & Maintainability

Modularity is a very important aspect in ADAM's design. Firstly, dividing the team into groups that work in parallel was the main reason for this modularity. Also, within each team, each member was insuring to do his task while reducing the dependency on other team members' tasks as much as possible insuring modularity. Because of this modularity, system's components can be separated insuring that if a component fails, the overall system can be easily maintained by replacing or isolating the malfunctioning component improving the maintainability of the overall system.

3.3. Speed

ADAM was built with a controller that insures a minimum speed of 1 mph and a maximum speed of 6 mph. However, under certain circumstances depending on the obstacles present in the environment, the speed might drop below the 1 mph. In that case, the controller would insure that within the last one minute, the average speed is more than 3 mph by keeping a history of the speed and by increasing the speed to even more than 6 mph (maximum is 8 mph).

3.4. Battery Life

For the four batteries that are connected to the DC motors directly, since the current consumption of the used DC motor is 1 A approximately, the battery life is about 3 hours of continuous use. However, while testing, we were able to run it for approximately 4 hours. For the other components, Table 2 shows the current consumptions of all several sensors and microcontrollers.

Table 2: Current Consumption

#	Component	Quantity	Currect Consumption
1	NovAtel SUPERSTAR II GPS	1	150 mA
2	HOKUYO URG-04LX LRF	1	500 mA
3	Surveyor SRV-1 Blackfin Camera	1	145 mA
4	Honeywell’s HMR3000 Digital Compass	1	35 mA
5	Dragon12-Plus	2	65 mA
	Total		960 mA

Based on that, the two batteries that are connected to the sensors and the microcontrollers should have a battery life of approximately 3 hours. However, since we are not using both batteries in series for all sensors (because some sensors require even less than 7.2 V like the LRF), we were able to get a battery life of 5 hours.

3.5. Reaction Time

A State-Space feedback controller with integrator was built to insure that the settling time (i.e. reaction time) would be less than 0.3 second. The controller was built in Simulink and simulated with a model for the system that was also built in Simulink.

3.6. Obstacle Detection Maximum Distance

Using the HOKUYO URG-04LX LRF, the obstacles can be detected from at most 4 meters from the sensor. However, the Surveyor SRV-1 Blackfin Camera can detect obstacles from even larger distance based on the flatness of the ground. With a completely flat ground, the camera was able to detect obstacles from over 8 meters.

4. Project Estimation

4.1. Cost

The cost breakdown is as shown in Table 3.

Table 3: Cost

#	Component	Price
1	NovAtel SUPERSTAR II GPS	$599.00
2	HOKUYO URG-04LX LRF	$2,375.00
3	Surveyor SRV-1 Blackfin Camera	$195.00
4	NPC-B81 DC Motors with Two Vishay Model 120e Encoders	$451.00
5	Honeywell’s HMR3000 Digital Compass	$675.00
	Total	$4295

4.2. Man Power

The number of hours worked by each team member is given in Table 4.

Table 4: Work Load

#	Team Member	Responsibility	Hrs
1	Hichem Zakaria Aichour	Team Leader	100
2	Muhammad Zulkifli	Vision Group	120
3	Navid Abbasi	Vision Group	150
4	Waqqas Khan	Navigation Group	130
5	Kamal Saadeddin	Navigation Group	120
6	Sivakumar Ukkirapandian	Navigation Group	140
7	Md Sheruzzaman	Path Planning & Control Group	130

5. Referances

[1] S. Koenig and M. Likhachev. D* Lite. In Proceedings of the AAAI Conference of Artificial Intelligence (AAAI), 476-483, 2002.

[2] I. Ulrich and J. Borenstein, "VFH+: Reliable obstacle avoidance for fast mobile robots", IEEE Int. Conf. Robotics and Automation, pp.1572 - 1577 , 1998.