Final Report

Autonomous Tracking Robot

ECE4007 Senior Design Project

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Executive Summary

The autonomous robotic tank demonstrates target acquisition, following, and targeting capabilities. Before a full scale prototype is built, it is useful to build a small scale model to show the technology's capability. It would be expensive to acquire an actual military tank to test the capability of the listed technologies in achieving full autonomy. The final unit including all engineering and production costs is estimated to be about $3,000. The tank uses a combination of IR motion sensors, an ultrasonic proximity sensor, and a webcam to autonomously track and fire at a human target. The IR sensors recognize a target has approached the robot and will be responsible turning the tank to face the target. The webcam uses a color tracking program running on the eBox 2300, which the tank uses to track a moving target from side to side, align the turret and fire at a target. The ultrasonic proximity sensor was used to read the distance between the target and the robot, determining when the robot should approach. The tank, successfully, autonomously tracks, targets, and fires as proposed, but the budget limited reliability due to poor sensor performance. Further improvements to increase accuracy would have been an encoder to keep track of the turret offset, a faster eBox to more efficiently run the color tracking algorithm, and include multiple ultrasonic sensors to reduce false distance readings.

Autonomous Tracking Robot

1. INTRODUCTION

The desire to minimize casualties in warfare led to the invention of the unmanned ground vehicle or UGV. UGVs are controlled either autonomously or remotely by crew members from a safe distance. Most, however, are remotely controlled and are primarily mounted with firearms. Taking this technology one step further, the DK-3 senior design group built a scaled down autonomous tank. Not only will autonomous tanks minimize casualties, they will also increase military strength without the need for additional manpower.

1.1 Objective

The autonomous robotic tank demonstrated target acquisition, following, and targeting capabilities. These capabilities display the underlying technologies behind the application of autonomously controlled vehicles to tanks. The tank used a combination of IR motion sensors, an ultrasonic proximity sensor, and a webcam to autonomously track and fire at a human target.

1.2 Motivation

Autonomous tanks would be primarily marketed towards the military and national defense. Before a full scale prototype is built, it is useful to build a small scale model to show the technology's capability. It would be expensive to acquire an actual military tank to test the capability of the proximity sensors, the IR motion sensors, and the web camera running the color tracking program, in achieving full autonomy. In building a small scale version of a potential prototype, these technologies can be demonstrated to interact together successfully with the embedded system, as well as provide accurate and effective autonomous tracking. In successfully building this small scale robot, the military would be motivated into building a full scale prototype for an autonomous tank.

1.3 Background

Autonomous vehicles are still in a phase of heavy research and design. Although other industries have interest in them, their primary interest is the military. Congress has mandated "It shall be a goal of the Armed Forces to achieve the fielding of unmanned, remotely controlled technology such that [...] by 2015, one-third of the operational ground combat vehicles are unmanned," in Section 220 of the National Defense Authorization for Fiscal Year 2001. DARPA offers millions of dollars in various autonomous vehicle tests through the DARPA Grand Challenge to advance the development of autonomous vehicles [1]. Thus far, the military has developed autonomous vehicles that gather information, transport goods, or work for extended durations, but they have not produced a fully autonomous battle tank [2].

Technological Components

The key building block needed for autonomous vehicles is sensors. Passive infrared heat sensors are used to detect motion and ultrasonic proximity sensors are used to determine the distance of an object from the vehicle. Without these crucial components, the vehicle is blind to its environment and is essentially useless.

2. PROJECT DESCRIPTION AND GOALS

The project engineers modified a 1/16th scale, radio-controlled (RC) tank mounted with and controlled by a mini computer. The computer attains input data from various components. IR motion sensors are used to detect the movement and relative location of the target. An ultrasonic proximity sensor determines the distance of the target from the tank. A web camera utilizes a computer tracking algorithm embedded in the computer. The goal for this project was to have the robot perform the following set of actions:

- Detect a moving target and rotate to face the target
- Follow the moving target
- When target stops, adjust itself to a specified distance from the target
- Adjust turret to aim at target
- Fire a projectile

The full-sized tank will be primarily targeted for use by the military.

3. TECHNICAL SPECIFICATIONS

Proposed autonomous tracking battle tank specifications are outlined in Table 1.

Table 1. Autonomous Tracking Vehicle Specifications

Attribute	Criterion	Specification
Target Firing Range	Need distance between turret and target	1.15m
Mounting Size	Need space for mounting eBox 2300	115 x 115 x 35 mm
Cone of Accuracy	Radial distance from target	5°
Motion Sensing Range	Need distance between each sensor and target	5m

The tank adjusts its distance from the target to a range less than 1.5m before it fires the projectile. If the distance is greater or less than this range, then the tank moves accordingly. For firing the projectile, the tank has a cone of accuracy within 5° from the target's center. The maximum distance that the tank senses motion is 5m away.

4. DESIGN APPROACH AND DETAILS

4.1 Design Approach

The autonomous tank consists of four main components: the computer, the sensors, the controller and the tank. Figure 1 shows a block diagram of the control flow.

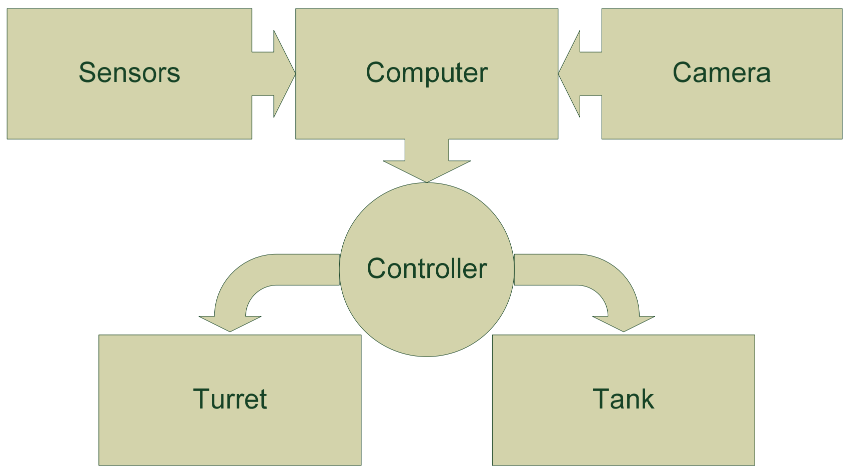

Figure 1. Control flow diagram.

Tank

The specifications for vehicle are summarized in Table 2.Table 1. Vehicle Specifications [8]

Attribute	**Specification**
Type	German Tiger
Scale	1/16th
Size	18"x9"x8"
Turret Rotation	320°
Firing Range	25m
Ammunition	Airsoft BBs
Reload	Automatic

Sensors

The sensors used are four Panasonic AMN23111 IR motion sensors, one Panasonic AMN21111 spotlight IR motion sensor, one Phidgets 1128 ultrasonic distance sensor and a Logitech Quickcam Pro 9000 webcam. The sensors will be arranged as shown in Figure 2. The position and facing of the AMN23111 sensors are shown in grey. The position and facing of the AMN21111, Quickcam Pro 9000, and 1128 are shown in blue. The Quickcam Pro9000 and 1128 are mounted on the turret while the other sensors are mounted directly on the tank's body.

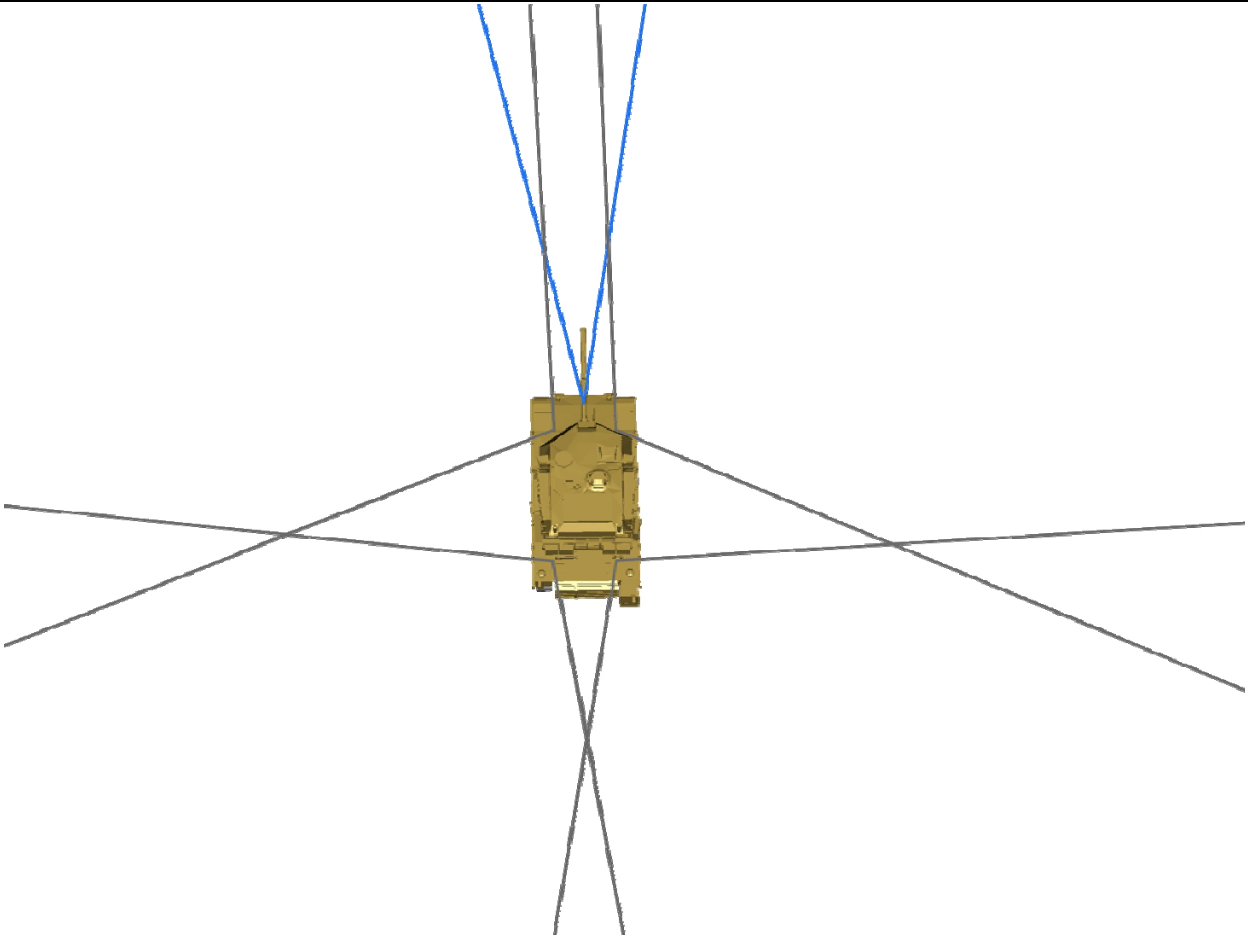

Figure 2. The sensor arrangement. The position and facing of the AMN23111 sensors are shown in grey. The position and facing of the AMN21111, Quickcam Pro9000, and 1128 are shown in blue. The Quickcam Pro and 1128 will be mounted on the turret while the other sensors will be mounted directly on the tank's body.

The AMN23111 and AMN21111 are mounted on the tank's body. They were chosen as IR motion sensors so the tank would not detect movement in all directions when it moved. The Quickcam Pro 9000 and 1128 are mounted on the turret to allow the tank to track with it when the body is immobile. The Quickcam Pro 9000 runs on USB 2.0 and captures up to 30 frames per second [10]. The 1128 has a range resolution of 1 inch [9]. Table 3 contains sensor specifications.

Table 2. Sensor Specifications

Attribute	**AMN23111** [3]	**AMN2111** [4]	**1128** [9]	**QUICKCAM PRO9000** [10]
Horizontal Range	100°	38°	N/A	71°
Vertical Range	82°	22°	N/A	71°
Number of Detection Zones	64	24	N/A	N/A
Detection Range	10m	5m	15.24cm-6.45m	N/A
Output Voltage	4.5-5.5V	4.5-5.5V	3.0-5.25V	N/A

Computer

The eBox 2300 is an embedded system that is mounted on the back of the tank. The eBox has a 200MHz Vortex86 SoC CPU with 128MB of onboard SD-RAM [7]. It takes input from the sensors and uses that information to control the tank. All of the sensors, except the Quickcam Pro 9000, produce digital outputs and connects to the digital input of the Phidgets 8/8/8 board, which connects to the computer. The kit has 8 analog inputs and 8 digital outputs [5].

Controller/H Bridges

The CV-HB 401 Dual H-bridge is used to control each individual motor on the tank. There are two motors that control the tanks movement. The H-Bridge can control two independent motors, so it is well suited for the application. The H-bridge produces up to 2A of current, and a maximum of 28V for motor control [6].

Phidgets Interface Board

A Phidgets LCD 8/8/8 interface board is used to connect the various controlling and sensing components to the eBox. The Phidgets interface board has 8 analog input ports, 8 digital output ports, and 8 digital input ports. The analog input ports measure voltages from 0 to 5V and are represented in software by values from 0 to 1024. The digital input ports simply return true or false depending on the presence or absence of voltage. The digital output ports generate a 5V TTL logic signal when the software is set high and 0V ground when set low. The interface board connects to the eBox via a standard USB plug.

Wiring Layout

The ultrasonic sensor and five infrared sensors are connected to the analog input ports of the interface board. Five digital output ports are used for sending signals to the H-bridge to control the track motors of the tank. Three digital output ports are connected to special relay circuits to turn on the motors for turret rotation and firing. The relay circuit used is shown in Figure 3. It consists of a 2N3904 BJT transistor, 1N4148 diode, G2R-1-E relay, 50 ohm resistor, and a 9V battery. When the Phidgets digital signal is low, the relay switch outputs a 0V ground signal. If the Phidgets digital signal is high, the relay switch will flip to the 9V rail and the output will power the turret motors. Two wires are used to control the rotation of the turret. One high signal and one grounded signal will rotate the turret a specific direction. Reversing the polarity of the wires will rotate the turret the opposite direction. Two wires are required to fire the turret, as well, but there is only one configuration needed. One wire is set high to turn on the firing motor. The other wire is always grounded so it does not require utilization of a digital output port.

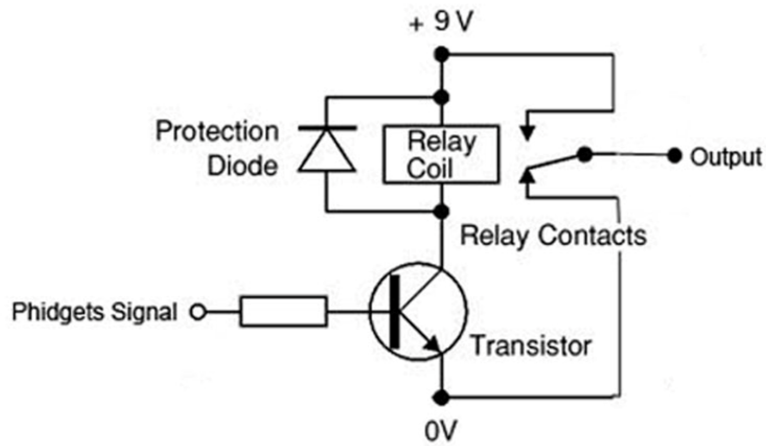

Figure 3. Relay circuit.

Algorithm Overview

Upon detecting the target, the tank turns to the closest edge of the quadrant in which the target was found. The IR motion sensors indicate human motion if a value greater than 380 or less than 620 are detected. These values correspond to voltages of 1.9 and 3.1V respectively. The sensor levels around 2.5V when no movement is detected. The tank begins to rotate in the direction of the target until the AMN21111 on the front of the tank detects the target. Since this sensor is shielded the threshold to detect motion is much lower. If a value of greater than 535 or less than 475 is returned, the target is assumed to be in front of the tank. The Quickcam Pro 9000 is then used to track instead of the motion sensors as the tank will be facing the target. If at any point the Quickcam Pro 9000 loses sight of the target, the tank will return to the start of the algorithm, searching for the target with the four AMN23111s. At this point, the tank alternates between corrective turning using color tracking and approaching the target until the 1128 reads less than 150 which corresponds to 1.15m. The tank approaches the target by moving forward for 100ms following the corrective turning and distance checking. Once the target is within range, the tank continuously does fine tune aiming with the turret using color tracking, since it moves slower and more consistently. Once the target is within ±5º of the blob center for .5s, the tank fires a plastic pellet.

Color Tracking

Because of the limitations due to the eBox's speed, the webcam's resolution is limited to 160x120 lessen computation. The pixels from the webcam are stored in a 2D array. The target color used is red. A pixel is considered to be red if the pixel's red value is large than the sum of its green and blue values. The pixels for each horizontal line are iterated though creating a node in a linked list for each consecutive group of target pixels. Then the linked list is iterated through grouping horizontal groups that are neighbors vertically. A running average of all the pixel's indexes is calculated for each group. If no group is larger than 150, the target is assumed to be lost. If the largest group contains more than 150 pixels, the tank turns by an amount determined by converting the average pixel offset to time the turret or tank needed to turn in ms, which was determined experimentally. The value, 150 pixels, was also experimentally determined to reduce false positives.

4.2 Codes and Standards

The purpose of the autonomous tank being proposed is to demonstrate the underlying technology behind autonomous vehicles can be effectively applied to full scale tanks; thus, it is a custombuilt product with no intention of mass production and has no standards imposed upon it. The full scale tank, however, has to be standardized for mass production and would need other specifications determined by the military.

4.3 Constraints, Alternatives, and Tradeoffs

Cost Constraints

The primary constraint upon the design was cost because the budget for parts, excluding those already owned, is a maximum of $403. The quality of the RC tank, sensors, and controller had to be reduced to maintain affordability. The number and type of sensors and the size of the tank were also reduced.

Size Constraints

Because the cost constraints determined the size of the tank, size constraints were placed on the rest of the parts as they are to be mounted on the tank. The German Tiger tank was chosen as it had the largest space behind the turret to mount the eBox.

Targeting Constraints

Since the target can move faster than the tank can turn, the tank is not able to reliably track it. The tank is has to stop before using the webcam to track or the frame is distorted further slowing down tracking.

5. SCHEDULE, TASKS, AND MILESTONES

A description of the detailed schedule, tasks, and milestones are included in the Gantt Chart located in the Appendix. The column titled names describes who will be working on each specific task. All writing assignments were done by the team as a whole. The majority of the hardware applications were handled by An and Chris. The OS programming and sensor software was handled by Chris. The majority of the code for controlling the tank was completed by Winton. Nathan stripped extraneous overhead features out of the camtest application used to bring in webcam images. The team as a whole tested and refined the tank's performance.

6. PROJECT DEMONSTRATION

6.1 Final Demonstration

The autonomous vehicle showed its effectiveness in a live demonstration. The vehicle was placed in a hallway at an arbitrary orientation. An was used as the target and had a piece of red foam attached to his leg for color tracking. There were three levels of demonstration. For each, the tank started tracking automatically after the eBox finished powering up. The eBox had to be restarted between each trial. For the first level, An remained stationary, and the tank successfully performed twice. For the second level, An moved around throughout each stage of the tank's algorithm to demonstrate the tanks tracking and following capabilities. The tank performed successfully once. For the third level, An moved around throughout each stage of the tank's algorithm and at a random point moved where the target would be lost. The third level was attempted three times. One attempt was successful. One attempt failed because while reacquiring the target, the tank stopped responding. The third attempt was neither a success nor failure due to interference; the tank locked on to other people in range of the tank's sensors while reacquiring the target.

6.2 Incremental Testing

Prototypes of the vehicle were tested in incremental stages. The initial stages proposed were:

Stage 1

The first stage will be to test each of the three actions listed above separately. This will be done by isolating each action and testing whether the software responds to a stimulus from the target correctly. All four of the infrared sensors will be tested separately to determine whether they can be triggered properly by the presence of the target. The video camera based tracking will be tested by aligning the vehicle so that it is already facing the target. The vehicle will then move toward the target, constantly correcting its course using video data. The ultrasonic sensor will be tested by placing the vehicle a known distance away from the target. Multiple readings will be taken at each distance to test the precision for the sensor.

Stage 2

The second stage of testing will be integrating two consecutive actions. First the vehicle will be placed facing directly toward a stationary target. The vehicle will travel at the target using the camera for course adjustments and stop after the ultrasonic sensor determines that it is within firing range. After these two actions are working together effectively, the first action will be incorporated into the test; the vehicle will have to locate the stationary target within the room before tracking it.

Stage 3

The final stage of testing will require the vehicle to track a moving target. The vehicle will first locate the target using the infrared sensors and then track and follow the target using the camera and ultrasonic sensor. The target will then move such that it is out of view of the camera so that the vehicle will have to locate it using the infrared sensors again. The vehicle will also be tested by having no targets in the room and a target that enters the room after a delay.

The actual testing stags differed slightly from the proposed stages because of difficulties with the color tracking algorithm. Stages one and three remained the same however, stage two happened in multiple steps. Color tracking was first tested with turret movement only to make sure that the algorithm was able to accurately track the target provided. The algorithm was then tested in conjunction with the tank movement. Once both uses for the color tracking were tested separately, the two actions were tested consecutively.

7. MARKETING AND COST ANALYSIS

7.1 Marketing Analysis

The autonomous tracking robot is being used to demonstrate the capability of the applied technologies to successfully track and fire at a target. This project was done as a proof of feasibility to a full scale prototype to save both time and money. For this reason, the robot will not be sold commercially. The product is targeted towards the military, aiming to draw a contract for implementing a full scale prototype. Since the tank was built as a 'pre-prototype', some of the parts were borrowed from Georgia Tech. The product was also built to 1/16th scale of an actual autonomous tank. If a full scale prototype were to be built, the cost would be considerably higher.

7.2 Cost Analysis

Development of the full scale prototype would require an outside contract from the military. The cost analysis will focus on if a company were to contract this team to build this small scale prototype to demonstrate that this system is a viable option in a full scale application. The estimated workload of each group member including all documentation, lecture attendance and outside meetings is estimated to have been about 80 hours. The prices in Table 2 describe the actual costs in producing the small scale prototype in an industrial or corporate setting, meaning donated and borrowed parts are included in the price. Profit per unit is estimated to be $770, or approximately 20%. The selling price is based on the fact that the item would be mass produced as opposed to being used to attract a contract to build a full scale prototype.

Table 3. Cost Analysis of Selling One Unit at $4000

All Materials [3]-[10]	$500
Assembly Labor	$200
Testing Labor	$120
Fringe Benefits, % of Labor	$100
Overhead, % of Matl, Labor & Fringe	$500
Sales & Marketing Expense	$1000
Technical Support Expense	$300
Amortized Development Costs	$650
Subtotal, All Costs	$3370
Selling Price	$4000
Profit	$770

The costs for materials were based upon the bulk price for the items, if available. The assembly of the product would likely be done by a technician, at an average salary of $20 per hour, taking approximately 10 hours total. The testing would also be done by either a technician or an entry level engineer at $20 per hour, taking approximately six hours [11]. The development cost for producing 10 units was based upon an approximate per unit development cost of $65. The remaining costs were approximations based on the cost of the materials and labor.

8. SUMMARY AND CONCLUSIONS

The tank autonomous tracks, targets, and fires as proposed, but the budget limited the reliability of its performance because of the sensors. Performance could also be improved by use of a faster embedded computer and a higher quality camera. Future work on the project would include adding an encoder to the turret so that its position could be much more precisely measured. Additional ultrasonic sensors could be added to take multiple readings and improve the accuracy of the distance sensor.

There are also two improvements that would make the tank more user-friendly. Push buttons that would allow the algorithm to be paused or reset would have improved the testing stages because we would not have needed to power cycle the eBox to restart a test. Hiding more of the wires and hardware inside the tank would have improved aesthetics and reduced the risk of cable being pulled or damaged by the tank or turret movement.

The tank functioned fully autonomously and was able to consistently acquire a target, track its target, and fire a projectile. Future work on the tank would improve performance by increasing the speed and accuracy of data acquisition and processing as well improve usability of the tank for testing and improve the aesthetics of the tank.

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10. Appendix A: Gantt Chart