Robot Hide and Seek

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1. Abstract

Although Global Positioning System (GPS) technology has been commercially available for over a couple of decades, its uses exceed the most common usage of personal navigation. This project focuses on the inter-communication between GPS systems and robots.

Using LEGO NXT bricks, RobotC programming, and other third party equipment, this project aims to have two autonomous robots playing a simple game of hide-and-seek with each other to investigate this connection. However, it starts much simpler – to have one semi-autonomous robot manually controlled searching for the other robot given a specific latitude and longitude.

In the future, GPS technology integrated with autonomous robotics can be applied to the military, unmanned aircrafts, and toxic environments.

2. Background

The GPS system used today has three predecessors. Launched in the 1960s, the Transit was the first satellite-based navigation system whose relative success led to more widespread research and the development of satellite technologies. The Timation, which was mainly used for two-dimensional navigation, was a system of two satellites that used quartz crystal oscillators to create very precise electric frequencies to measure time accurately to within a nanosecond. The last of the three, System 621B, was important for its use of sixteen satellites. Based on the testing of this system, researchers discovered that at least four satellites are necessary for three-dimensional – longitudinal, latitudinal, and altitudinal – navigation.

In 1968, the Department of Defense established the Navigation Satellite Executive Group (NAVSEG). Within five years, a new navigation system, which was based on the Timation's eight hour orbit patterns and the signal and frequencies of System 621B, emerged. This system, which used twelve hour orbits is now known as NAVSTAR GPS.

On June 26, 1993, the United States Air Force launched the last of the twenty-four NAVSTAR satellites that now make up the Global Positioning System, known colloquially as GPS. The navigation system took traits from its three predecessors, the Navy's Transit and Timation systems, and the Air Force's System 621B [4].

Originally, the navigation system was a lot less accurate than it is today, a fault owed to Selective Availability. Before 2000, when President Bill Clinton ordered Selective Availability to be turned off,

private users of GPS received purposely scrambled signals from the satellites. The intention behind this was so the military would monopolize a more powerful and accurate unscrambled signal. Selective Availability made it so that there would be an inaccuracy of about one hundred meters for civilians. Conversely, after Selective Availability was turned off, civilian GPS navigation was accurate to within twenty meters [8].

Since then, GPS technology has been steadily advancing. Presently, it is capable of mapping any location around the world in great detail, which is demonstrated by programs such as Google Earth. It can also update the position of people and vehicles in real-time and simultaneously track multiple targets. GPS tracking is now available at a low cost to a variety of industries, including aviation, shipping, and personal navigation [5].

The most prominent use of GPS technology is for military purposes, from individual uses of navigating in dark or unfamiliar territories to guiding a missile across great distances. While the military uses GPS technology to track targets and for reconnaissance, the technology can also be used to track allies during operations such as search-and-rescue missions.

Private enterprises also use GPS technology for tracking purposes. Construction companies, for example, use GPS tracking of staff vehicles to ensure that employees are not using the vehicles for personal use nor entering restricted areas. The technology can also aid in the tracking and recovery of stolen goods [2].

On a smaller scale, many people around the world enjoy geocaching, a hobby in which different people leave gifts at a certain locations and publish the latitude and longitude coordinates for others to find them. For this project, GPS technology in combination with robotics is used to recreate a game of hide-and-seek.

3. Design Process

Three milestones were set for this project, the last of which was to make two autonomous robots. Ultimately, the robots would play a game of hide-and-seek, with one running and the other tracking it with GPS. Firstly, the project starts with a single robot controlled by a hand-held controller and following that, a single autonomous robot programmed to find a second stationary robot without user assistance.

The robot was carefully designed and built with considerations for its dimensions. The robot has a n9bo0p small width and length so it was able to dodge obstacles more easily. It is relatively flat to maintain a low center of balance. A high robot would be too top-heavy and unwieldy when making sharp turns. Therefore, by building it lower, the robot does not run the risk of falling over. Finally, the wheels chosen have good traction and are able to perform well on various materials, including carpet, wood flooring, and concrete.

For the first phase of the project, the coding was organized into GPS parsing, triangulation, encoding, and decoding. All of the logistics, such as data types, needed to be planned out before-hand to make integration easier. The program was also integrated in steps. First, it was ensured that the encoding and decoding processes worked in tandem. Then, the parsing and triangulation codes were combined before integrating the entire program together.

4. Hardware

The LEGO kit contains various sensors, as well as the NXT brick (Figure 1), which is the brain of the system. Program code, which is the basis of the robot's actions, can be downloaded to the NXT either through Bluetooth (Bluetooth Class II

V2.0 compliant) or a USB cable [1]. The NXT brick contains two microcontrollers, one of which is a 32-bit ARM7 microcontroller with 64 KB of RAM and 256 KB of program storage space that is used for running code. The other microcontroller is an 8-bit microcontroller with 512 bytes of RAM for interfacing with the sensors. The brick has three output ports where motors can be connected to, four input ports for sensors, and a USB port. The sensors and motors are connected using a proprietary six wire cable similar to a telephone cable. The more complicated sensors, such as the compass and ultrasonic sensors, use I2C technology to communicate. The fourth port also includes a special function that allows it to communicate with other NXTs plugged into it. Text and images can be displayed on a 100 x 64 pixel LCD graphical display. The brick is also capable of playing sounds [10].

Figure 1. The NXT brick has a variety of functions and acts as the brains of the robot.

The Qstarz 818x GPS, which can transfer its position at a rate of up to 5Hz, is attached to the robot (Figure 2). To communicate with the GPS, Bluetooth, a wireless communication technology that uses radio waves, is used. It was invented by Ericsson engineers in 1994 and operates in the unlicensed 2.4GHz band. It uses an advanced form of frequency hopping to avoid interference. However, Bluetooth is only meant for distances of fifty meters at most. Most Bluetooth chips in mobile devices are Class II, meaning that they have a maximum effective range of ten meters (thirty-three feet) and draw around 2.5mW of power [9].

Figure 2. The Qstarz GPS was used to determine the location of the target and the robot.

This project utilizes various types of sensors in this project, the first of which is a touch sensor (Figure 3) that operates with binary logic. When the button on the sensor is pressed down, the sensor is assigned a value of "1." Otherwise, if the button is not pressed down, the sensor is assigned a value of "0."

Figure 3. The touch sensor detects when the button is pressed and released.

An ultrasonic sensor (Figure 4) is another sensor attached to the final robot. The ultrasonic sensor measures distances by calculating the time required for a sound wave to be emitted, bounce off an object, and return to the sensor. The sensor can measure distances of up to two hundred and fifty-five centimeters with a precision of +/- three centimeters. Although this sensor is fairly reliable, it becomes inaccurate when the object being detected is made of a soft fabric that absorbs sound waves or when the object has a curved surface [10].

Figure 4. The ultrasonic sensor is used to detect obstacles.

The last sensor, the HiTechnic compass (Figure 5), contains a digital magnetic compass that measures the earth's magnetic field. Using that measurement, the heading angle is calculated to the nearest degree. The compass automatically updates the reading one hundred times per second [7].

Figure 5. The compass sensor calculates the robot's heading angle.

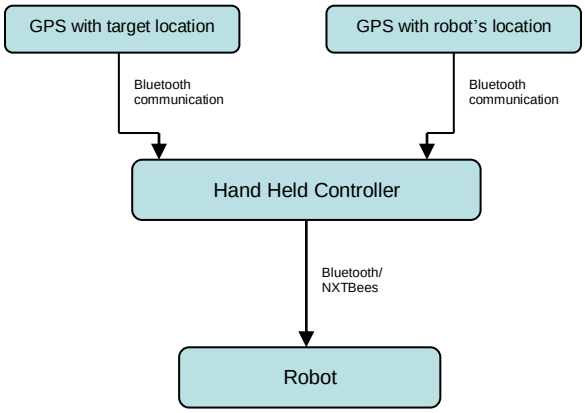
Additionally, the servo motors we connected to the NXT have a built-in encoder that tracks the degrees the wheels have rotated to +/- one degree [10].

In order to communicate between the two NXT bricks, a device called NXTBee was used. The NXTBee is a third-party component that enables wireless communication between multiple NXT bricks. It uses the XBee wireless communications standard and plugs into the 4th sensor port on the NXT, which is a special high speed communication port. Essentially, two NXTBees simulate a physical wire between the two bricks. When powered with a nine volt battery, the maximum range of the units is around 1.2 km. However, when using it without the battery, as was done in this project, the range is only about one hundred meters [11].

5. Software Highlights

In regards to software, this project uses RobotC to code the programs that control the robot. First released in 2005 by Carnegie Mellon University, RobotC is based on the C language, but has specialized commands used in robotic programming. It uses a firmware that allows for efficient floating point processing and allows for lower level access than the standard firmware. The debugging feature is also very sophisticated, allowing programmers to run the code step by step to isolate bugs.

This project consists of three major milestones, the first of which involves one GPS receiver placed as the target, TargetBot, and another receiver on the moving robot, EngineBot (Flowchart 1). Originally, the hand held controller was going to utilize Bluetooth to communicate the motion commands to the robot. The hand held controller would probe the location from the TargetBot and navigate the EngineBot by sending the motion commands to it. Due to limitations in the Bluetooth connection (refer to Section 7-Issues) though, the communication was switched to using NXTBees instead.



Flowchart 1. The overall communication plan for the first major phase of the project.

For the next milestone, an autonomous robot, the EngineBot, is programmed to self-navigate to reach the TargetBot by extracting the coordinates from both the GPS receivers.

The final milestone replaces the stationary target GPS with a robot, TargetMovingBot that was programmed to move around. There is one more significant difference between the second milestone and this one. In the second portion of the project, EngineBot only has to ask for the GPS coordinates of TargetBot once; since TargetBot is stationary, the coordinates would stay the same. In comparison, in this portion, in order for EngineBot to keep track of and chase TargetMovingBot, it needs to constantly probe the coordinates from both its own GPS, as well as that of TargetMovingBot.

6. Experiment

The practical aspect of this project was completed in six phases.

6.1 Initial Learning Curve

As we were new to the technology, both the software and hardware, the first step is simply to learn as much as we can about how to use them. This includes getting familiarized with the RobotC language and the LEGO Mindstorms kit. In this initial phase, we also looked into triangulation, which is the computing of a position with knowledge of two angles and a side, and dead reckoning, finding location in reference to a pre-determined point, with longitudinal and latitudinal coordinates. GPS coordinates are reported in the form of DDMM.mmmm (degrees, minutes, seconds), which is then converted to a universal standardized measurement in meters.

6.2 – Data Parsing

Since the robot navigates using GPS, one of the most crucial steps is to obtain the longitudinal and latitudinal coordinates. The GPS also sends data about the number of satellites used to obtain the data and the accuracy of the data itself. The accuracy increases proportionally with the number of satellites used.

The NXT actually receives the coordinates as a stream of characters, not numbers, so the GPS data had to be parsed. The American Standard Code for Information Interchange (ASCII) assigns each decimal number a character or value equivalent. For instance, the GPS data number 48 is actually equal to zero, 49 to 1, 50 to 2, and so on and so forth. By subtracting 48 from the received data, the "normal", so to speak, equivalent can be obtained.

The next portion of this phase is to compile the numbers together to form a coordinate in the format DDMM.mmmm, degrees, minutes, seconds. The most effective way to receive the GPS data string, due to the software RobotC's maximum 19-characters string restriction, is to get one character at a time from the GPS Receiver. One precaution that is taken in the code is in consideration of the fact that information from GPS satellites is sent constantly to the NXT, and the NXT may start receiving data in the middle of the data string. Theoretically, losing data in this particular case was not likely because, taking into account the processing speeds of the NXT and Bluetooth, and that our GPS receiver operates at 5 Hz, there is enough buffer time. However, the code is written in simulation of a case in which data is liable to be lost. In order to do this, it is necessary to distinguish between the beginnings of each string by looking for the header, a dollar sign ($). This is a step necessary to any GPS parsing program, even with the most sophisticated technology. Then, because the GPS sends data in various formats, the first section of the string is

parsed to determine whether or not it is GPGGA, the format the code this project requires. After receiving and parsing an entire string of coordinate data, it is put together in the DDMM.mmmm format. Then, the coordinate is converted to seconds, thus completing this phase of the project.

6.3 Phase III-Triangulation

After receiving data in the DDMM.mmmm format from the GPS receiver, the robot needs to autonomously determine how to navigate towards the desired latitude and longitude.

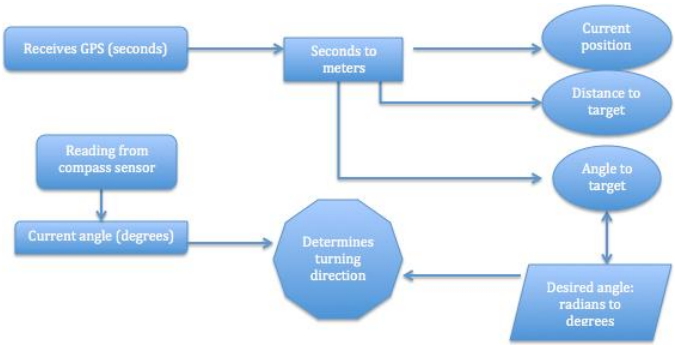
First, the robot needs to determine the intersection point of the two locations, and convert the points into meters by using the Universal Transverse Mercator (UTM) conversion. Next, the angular difference between the current location and the destination needs to be determined using basic trigonometry. The third is the calculation of the direction that the robot is facing using compass data. The last step of the process is the optimized judgment of which direction to turn (and how much) based on the difference between the two aforementioned values.

In summary, after receiving latitude and longitude values from the GPS receiver, the NXT-brick converts the values into meters based on the Universal Transverse Mercator (UTM) coordinate system and uses trigonometry to determine the angle between the robot and its target in degrees. The returned value, based on the 2D Cartesian coordinates, is a degree value between 0 degrees and 359 degrees, in which 0 degrees represents East, 90 degrees represents North, and so on. A major problem is that the arctan function in RobotC only returns values between -90 and 90 degrees. To counteract that, the code has to use logic to help the robot determine what quadrant the true angle is and subsequently, what the true angle is between 0 and 359 degrees. In this step, the robot also calculates the distance between itself and its target in meters using Pythagorean's Theorem.

The second step in this process is to determine the angle that the robot is facing. However, it returns angle values based on polar coordinates from Truth North or Magnetic North (0^o). Thus, the code has to convert the angle by subtracting 90 and inverting the result.

The third step in this process is to determine the turning direction based on the two calculated angles. In this program, the robot is told to turn left if the desired angle was up to 180 degrees less than the current heading of the robot. In contrast, the robot is programmed to turn right if the desired angle is up to 180 degrees more. In addition, a small tolerance value is added in anticipation of the sensor being somewhat inaccurate. While testing the robot, for example, there were discrepancies up to around 10 to 15 degrees.

The logic for this process is represented by Flowchart 2.



Flowchart 2. Determining turning direction using the GPS data.

6.4 Phase IV-Communication System

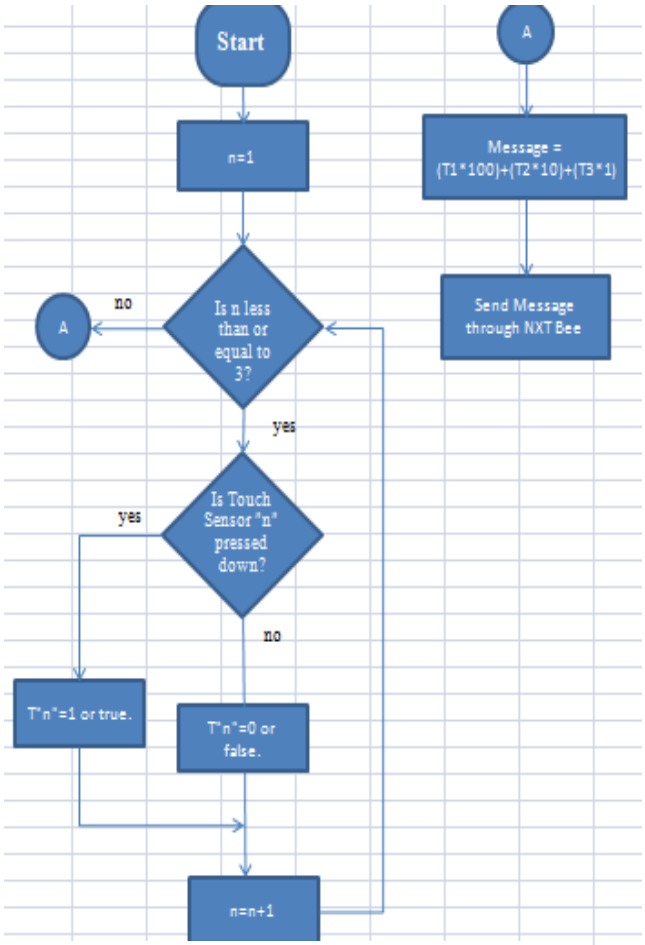
Phase four establishes the premise of a communication system between the robot and a hand-held controller that would direct the robot's movements. The controller features three touch sensors. By triggering these sensors in different combinations, the user would be able to tell the robot to go forward, backward, left, or right. The sensor

data is encoded using a somewhat binary system (for example, all sensors pressed down would be 111, while no sensors pressed would be 000) and the controller then sends the robot the data via Bluetooth – later switched to using NXTBee. The robot's NXT, upon receiving the message, decodes these binary values into a decimal number. Essentially, when the left trigger is pressed down, the computer adds a hundred to "x." When the middle trigger is pressed down, ten is added. When the right trigger is pressed down, one is added to "x." For example, when all three are pressed down, x=100+10+1=111. These values are coded into the mobile robot and each corresponds to an action. The NXT decodes the binary signals and determines which way the robot should move. The following state table (Table 1) shows which triggers need to be activated for which action.

Flowchart 3 shows the logic of this process.

Function	T1	T2	T3
Stop	0	0	0
Go Forward	1	0	1
Go Backward	0	1	0
Left Turn	1	0	0
Right Turn	0	0	1

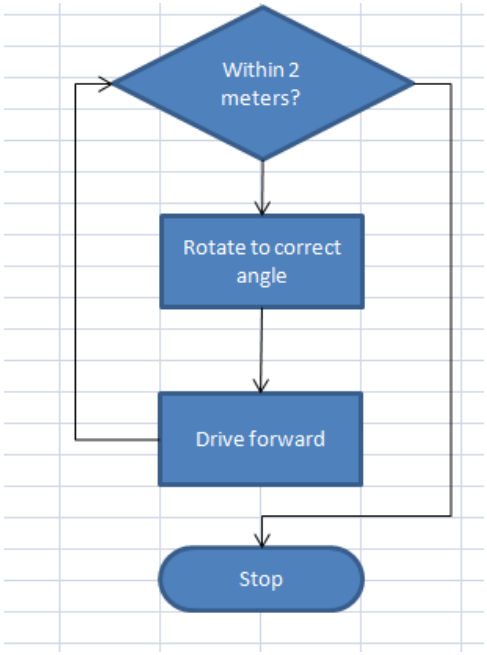
Table 1. State table for the controls.



Flowchart 3. Encoding the touch signals

6.5 Phase V-Robot with Stationary Target

The fifth phase of the project involves having the robot drive itself to a stationary target robot mounted with its own GPS transmitter. Therefore, all of the code needs to be moved from the handheld controller to the mobile seeker robot itself, and the compass is positioned on the robot. The compass needs to be mounted about four to six inches from the motors, otherwise the magnetic field from the motors would affect the compass reading. At this point, the code turns the robot in the correct direction, then moves forward, constantly checking to make sure that it is pointed the correct way. If not, the robot will turn and correct itself before moving until the robot is within two meters of the target, at which point it stops, as shown in Flowchart 4.



Flowchart 4. This shows how the autonomous robot navigates to the target.

The target robot and the seeker robot communicate when the program is run. When the seeker robot gets a fix on the target's GPS coordinates, it will self-route itself to the target location. To communicate, when the GPS is connected to the robot, Bluetooth cannot be used so two NXTBees were used instead.

6.6 Phase VI-Extended Challenge, Two Mobile Robots

The sixth phase of the experiment, a bonus challenge to the project, involves two moving, autonomous robots, each equipped with a GPS receiver. Due to time constraints, unfortunately, we were not able to complete this part of the project. Essentially, what would've happened in this phase, the target, stationary in phase V, is replaced with an automated robot moving randomly, sending out latitude and longitude. The finder robot has to move towards the specified latitude and longitude, and chase the target robot. Instead of the finder robot being manually controlled to find a static target, this phase features a program to self-route itself to the target. Meanwhile, the target robot will run around randomly carrying its own GPS receiver. It sends out its continuously changing GPS coordinates to send the changing locations via the NXT-Bee communication device. This process requires the same parsing know-how used in Phase Three.

The finder has the role of, respectively, receiving the information, receiving information about its own location, calculating angular difference between the two locations, determining which direction to turn, and navigating a certain distance before it recalibrates after receiving data about the target robot's new location. The target robot also requires a certain degree of artificial intelligence. Ideally, it would start a certain distance from the finder and move randomly while sending information about its location to the finder.

7. Challenges

7.1 Limitation of Available Channels via Bluetooth

Originally, it was intended to have the controller (ChaserBot) communicate with its own GPS and the target robot (TargetBot) at the same time on two different Bluetooth channels. However, in order for the controller to communicate with the GPS, the NXT Brick needs to communicate in raw mode. The root of this issue may be in the RobotC Bluetooth stack implementation, or it may be a limitation of the firmware requirement inherent to the NXT controller hardware. This issue is still unclear. When the controller communicates in raw mode, it can only have one Bluetooth channel open at a time, thus making it impossible to connect to both the GPS and the remote TargetBot. Therefore, in order to leave the Bluetooth connection open to use for the GPS, NXTBee, the LEGO

Mindstorms's version of the Digi XBee radio device, was used. The NXTBee uses XBee radios to wirelessly communicate and allows connections to multiple channels. Thus, the ChaserBot will collect coordinate data from the GPS via Bluetooth while another network channel is established with the TargetBot. The TargetBot, in turn, will have a similar infrastructure. It probes its own coordinates from its own carried-on GPS receiver and then broadcasts its location via XBee network technology.

7.2 Lack of Testing Locations

Another problem that was faced over the course of the project was with testing the robot. Since the project relied heavily on GPS measurements, the robot had to be tested in areas where there was a strong GPS signal. GPS signals are easily blocked or altered by tall buildings or trees, or enclosed spaces. Therefore, whenever the robot was to be tested, it had to be outside in an open field. This issue is common with all GPS receivers, even the most advanced ones. In addition, the choices for locations to test the robot were limited by the terrain of the location. In order for the robot to be able to easily navigate around the area, the land had to be flat. There could not be any ditches or hills in the area. The presence of these obstacles could tip the robot or set it off course. The combination of these two requirements severely limited the number of places at which the robot could be accurately tested.

7.3 Floating Point Calculations

While parsing the GPS data, there were some problems. When the GPS sends the information regarding its longitude and latitude to the robot, it is in the form DDMM.mmmm. Originally, the code tried to have the NXT Brick work with the entire string of numbers all together. There were some problems with doing it this way. It was discovered that in order for the robot to understand these numbers, they need to be separated into degrees, minutes, and seconds. The problems that were present were due to the fact that the NXT Brick cannot simply use the entire number due to the limitation in the number of bits that it can handle. All computers have this limitation, as they can only handle a certain number of digits at a time for a single piece of data. Therefore, the data had to be parsed into separate integers. This process is demonstrated by the pseudo-code below:

```
GPS measurement = 78.12345678
degree = GPS measurement as
      an integer = 78
minute = GPS measurement –
      degree * 60 = .12345678
      * 60 = 7.40736, but you
      only want the value 7
seconds = full minute value –
      integer minute value *
      60 = 7.40736 – 7 * 60 =
      .40736 * 60 = 24.4416
```

This process will allow the NXT Brick to be able to easily work with the GPS measurements while maintaining a high degree of precision and will allow the robot to locate its target within an area of one meter.

8. Future Improvements

There are many ways that the project can be improved in the future for smoother performance. We faced limitations in resources, which hindered us from testing the more advanced limits of GPS-autonomous robotics integration.

The language (RobotC) was easy to learn, and the sensor compatibilities were expansive. On the other hand, while the basics of RobotC and the NXT brick were easy to pick up, it is difficult to become fully intimate with all of their functions in the limited time that was allotted for this project. One suggestion for future research is that researchers should either already have

a background in RobotC or be given more time to learn its full capability.

The technology used was not up to par with the accuracy the project required. Since the robot operates on a small scale, precision is required. Civilian GPS technology has an error margin of at least 1 meter. The GPS receiver used in this project is stated to have an error margin of around 3 meters. So, in order for the robot to find its target more precisely, more advanced technology would be needed. Understandably, the technology required is not necessarily in the budget for this project.

One way to improve the final results would be to include obstacles between the two mobile robots to make the experiment more realistic. In this case, the robots must use sensors, like the ultrasonic, to detect and avoid obstacles while maintaining navigation. However, this goal would require a much longer time period to achieve. It would require several months and a more powerful platform to be able to successfully avoid obstacles.

9. Real-World Implementations

For the military, integrating GPS systems and autonomous robots can be employed in the rising global warfare between unmanned aerial vehicles (UAV) and drones. In fact, drones have recently become the primary vessel of combat in the Middle East. Furthermore, by researching and developing this technology, the military can improve their search and rescue operations to save soldiers' lives. Research is already being done in this area. For example, every year the Defense Advanced Research Project's Agency hosts a competition for automated vehicles called the DARPA Grand Challenge. In 2012, the agency has extended the requirements: the vehicle must be driven by an autonomous robot, which will navigate using GPS technology to an unknown location. It will then have to complete a series of tasks, such as fixing a pipe and climbing a ladder [3]. As a follow up, by making use of the Global Positioning System, robots would be able to eventually navigate battle fields by them selves and search secluded areas. This would minimize the loss of human life in search and rescue missions.

Also, the US military makes use of Paladins, which shoot long-range GPS guided missiles, such as Excaliburs. However, Paladins are the size of and look similar to tanks, but they are not as heavily armored [12]. Although they are very useful weapons, they and, by extension, their crews can be very easily destroyed. By implementing GPS navigation and the autonomous robot technology, the Paladins will be able to navigate without a crew and minimize loss of human life.

Robots can also be sent to defuse bombs or remove explosives. Planted improvised explosive devices (IEDs), otherwise known as roadside bombs, are often detonated by insurgents when they see a human or a vehicle. As robots are more compact, they would be harder to notice.

Presently, the military makes use of robots, such as the Talon IV MTRS. There are four cameras mounted on the Talon, but the conflicting views from these cameras can make the navigation process disorientating. Furthermore, as the robot moves farther away from the control center, the cameras start to lose connection and the resulting static makes navigation difficult. Also, training soldiers to be able to operate these robots take time. As of now, soldiers train using a video game simulation, for example the Robotic Vehicle Trainer developed by Picatinny Arsenal. As real as these simulations are, they are not enough to ensure that soldiers are fully prepared for the reality that is war. Unprepared soldiers can panic when they find themselves on a real battlefield, which can lead to the failure of

the mission, or the destruction of the robot. The games themselves take time and funding to make. By making robots, which can defuse bombs be able to navigate themselves through the battle field, essentially the military can cut out the "middle-man," saving time on training soldiers and funding for creating games. They would be easier to operate as well; for example, on the Talon, the robot is not able to move forward and move its gripping arm at the same time due to the controller's restrictions.

Similarly, deep-sea retrievals where manned navigation is impractical or unsafe and unmanned aircrafts would benefit greatly from autonomous robots aided by GPS systems. As technology improves, and unmanned aircrafts become more reliable, they open a world of new information for scientists. For example, an autonomous aircraft would be able to operate in storm or hazardous environments and collect data without any risk to the pilot. This data can be used to fight wildfires more effectively as well as better understand the way the storms work [6].

Furthermore, these robots could take the place of human workers working in nuclear or toxic environments. Radiation is detrimental to human workers, but by having robots clean up a contaminated site, human lives do not have to be risked, and the robots should come to no harm as they have no cells, which can be affected by radiation. These robots, though, would have to be built with material that would resist corrosion.

10. Conclusion

The final result of this project is an autonomous robot, made using the LEGO Mindstorms kit and RobotC programming language, that is capable of navigating to a stationary target. Using GPS technology, this robot can determine its current heading, calculate the angle it needs to turn in order to be facing the target, and move itself accordingly until it reaches that target. Further research into the integration of autonomous robotics and GPS technology has the potential to develop numerous new militaristic and scientific technologies.

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