Robotic Formations

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***Abstract*— Using simulation to test robot formation and shape change is beneficial in terms of time and money. This paper discusses robot model design and testing in the Webots mobile robot simulation software package. The motivation for this research involves forming evenly-spaced grid patterns with a team of mobile robots for future use in seismic imaging. A team of robots is incrementally designed and tested by incorporating sensors and altering each robot's controller. Challenges encountered throughout the process as well as design issues are discussed. Attention was given for each robot to travel efficiently from one location to the next. Simulation images of robot details and shape transformations are displayed as results of this research.**

Keywords: mobile robotics, robot team, seismic, simulation

I. Introduction

The two primary objectives of our research was to successfully create a robotic simulation that shows how numerous robots will assemble in order to collect seismic data, and build detailed individual robots. In contrast to the human approach of physically deploying and retrieving seismic sensors, robots would instead be used to perform this task. Once a designated location has been determined, each robot will plant its seismic sensor (geophone) and collect the vibration data after the seismic source has taken place. With the use of robots, human life is not at risk. Due to the harsh and dangerous weather conditions in the Antarctic and Greenland environments, robots would replace manual labor. With a team of robots, we will be able to collect a large amount of data over a shorter period of time.

We have used a 3-D graphical modeling program called "Webots" to simulate how a team of mobile robots will assemble into grid formation and migrate from one formation shape to another. Webots is a mobile robot simulation software package that allows one to model and test robots in a world created by the user. This program integrates physics as well as controllers to validate and test different robot duties and methods. Using Webots, we created a robot team to use for testing different shape formation changes. The formations are in different shapes and patterns in order to follow their desired transformation paths.

II. Background

The Center for Remote Sensing of Ice Sheets (CReSIS) is a science and technology center that helps analyze climate change and ice sheets using the latest computer-orientated technology. As students, we are able to learn and enforce our knowledge of disturbances within the polar ice sheets to help better model potential sea level rise. CReSIS also provides diversity among the next generation of researchers that will help shape the world of tomorrow.

In order for CReSIS to get an approximate measurement of what is beneath the ice sheets, seismic sensors, or geophones, are used. A seismic source (typically dynamite) sends vibration energy into the ground. Depending on how fast the vibrations reflect back to the surface, seismic sensors can be used to create images to help us better determine whether water or till lies beneath the glacier's bottom surface.

Formations are used in this process for several reasons. With the robots being in a specified formation, it allows for the operation that is being performed to be organized and fast. While the robots are in formation, it will ensure that each robot is equidistant from others so that the robot's sensors will not affect the others' desired paths. By having the formations in certain shapes, it allows the collection of 3-D images of the subsurface. The formations were chosen to be a combination of square and rectangular arrays because it will show how the layers change within the subsurface volume. This type of information cannot be gathered if the robots are in a typical straight line because it will only return a 2-D planar subsurface image.

In addition, when dealing with seismic sensors and formations, spacing is very important. The smaller the spacing between each planted geophone, the shallower and detailed the image will be. If the geophones are planted further from one another, it allows us the measure at greater depths but sacrifices near-surface detail. By using formations to collect seismic images we are able to retrieve data in a fast and efficient manner.

III. Approach Taken

Our first step was to sketch out on paper the different shapes we wanted our robots to change in. In earlier efforts, we discussed using robot team techniques rather than using one larger robot to pull the others by cable to plant the geophones. After a long period of debating, we decided on the approach to use nine robots. We chose nine since numerous formations can be formed using a team this size. On paper, we made four different formations that our robots could possibly form and change between. Our first sketch consisted of all nine robots in a straight line, with each robot moving straight out to different points in order to spread out the seismic sensors.

In order for us to begin working with our robots in Webots, we had to create a scene in which our robots would function. This is termed a "world" in the Webots software package. Our world was comprised of lights which would give our creations some realistic relationship to the world and a platform to insert our robots on. Four lights were created to accomplish this. Creating lights in Webots is essential since all the worlds need to provide light for the background and to see the robots.

The platform was made up of a grey solid base with four bounding objects (walls) around them so that the robots couldn't pass through them when programmed to move around the scene. The bounding objects are created to take the shape of walls but have an invisible outline so they wouldn't show when the robots are actually running.

A. Robot Details

Finally, it was time for us to create the robots from scratch. We initially planned to have three different types of robots: Leviticus, a yellow robot; Melanie, a pink robot; and Nathan, a blue robot. The basic shapes of the robots were made up of a perfect cube with a generic color. In order to give the robot some detailed characteristics, the "children" component was edited to add color and two wheels to the robot. We faced a problem when it came to setting the rotation of wheels to drive straight. If the rotation of one wheel is off, the robot may not move at all because one wheel may be rotating straight while the other could be turning the opposite direction. It took us a while to get both wheels to rotate in the correct manner.

The next step was to add sensors to the robot. Sensors are an essential tool to any robot in Webots since they allow the robots to see, provide location information, and prevent them from colliding with obstacles (such as walls). Two sensors were created and placed on the upper front portion of the robot, which made it look like it had two eyes. This initial and improved robot designs are shown in Figures 1 and 2, respectively.

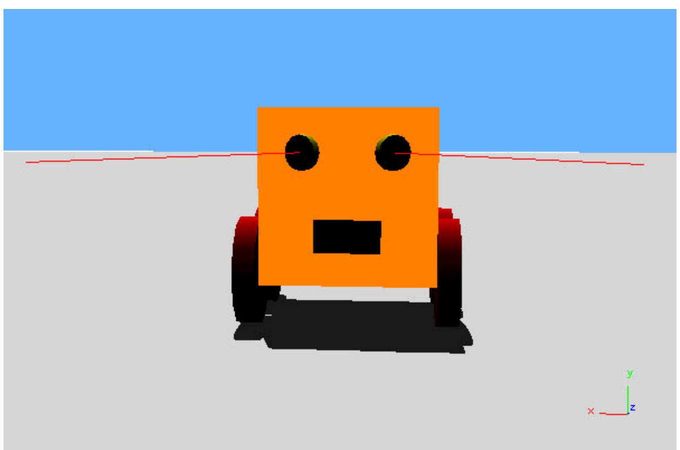

Fig. 1. First Robot Design

After completing the planned shape transitions, it was time to improve the detail of the robots to make them more realistic, attractive, and useful. Instead of a typical cube-like shape, we wanted to give the robots a unique look, different from the previous models. To begin, we removed all the accessories on the robot in order to have a clean slate. We shortened the height of the robot so it would look more rectangular than cubicle in shape. Next, we began adding accessories to the robot. We wanted to place the three sonar sensors on the back of the robots rather than the front, and place them on a more rounded surface. We gave the robot more of a rounded shape on both ends by adding six cylinders to the body component.

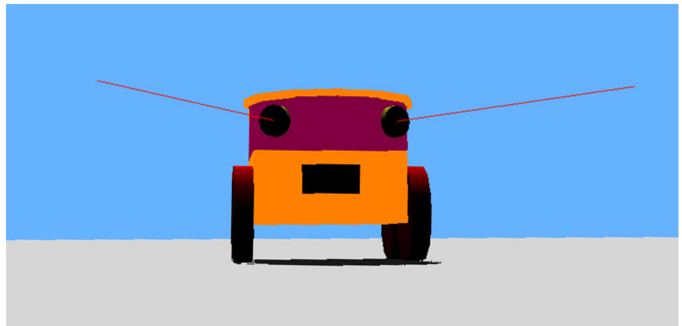

Fig. 2. Improved Robot Design

Eventually we added a black box to the back of the robot which represents the power source, a wireless antenna on the top for communication, a global positioning system (GPS) for accurate positioning information, and a laser range-finder in the front of the robot which functioned as a camera to provide distance information. The final robot design incorporated four wheels. This final robot design is shown in Figure 3.

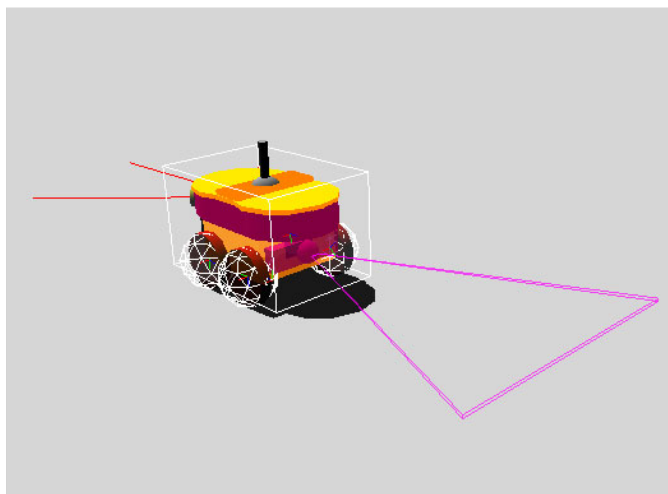

Fig. 3. Final Robot Design

B. Shape Transitions

After the creation of our robots was complete, editing the controllers for each robot was our next step. We decided to start with a simple, single line formation. For the yellow robots, we wanted them to all begin in a straight line, rotate to a new location, and stop. We began editing their basic controller by adding onto the conditional statement behaviors already in the program.

At first, we had difficulties getting the wheels on the robot to rotate the correct way. When we fixed this problem, we had to figure out how far we wanted the robot to go out prior to and after the rotation. Once all the yellow robots were functioning correctly, we used the basic foundation of the yellow controller and transferred them to the blue robot controllers. The difference was that the blue robots needed to rotate and travel the opposite direction. Changing a few positive and negative signs within the controller accomplished this. For the pink robots, we simply wanted them to travel straight but stop at different locations and distances. This was done by altering the conditional statements in the controller as we had before to achieve the desired functionality.

Our next formation consisted of all the robots beginning in a square shape to later end in a triangle shape. This formation consisted of some robots to rotate in place in order to get to their next destination point. We had to figure out the shortest transition each robot would have to make in order to make them travel more efficiently. We faced another problem with this transformation: the robots needed to rotate twice instead of once which was a lot harder than anticipated. We spent the next few days trying to figure out different ways for our robots to move and how to rotate them twice at the same time.

After coming up with the final design, we experimented with the team's controllers. We realized we had to basically double the conditional statements and variable declarations. One of our first problems with the robots during this shape transformation was that some of them weren't turning due to their given coordinates on the X- and Y-axes. We originally thought we could give the robots on the right side the same coordinates on the left and change signs, but did not turn out to be the case. Since our robots weren't exactly aligned in the center of the world, we had to adjust for new coordinate values for our robots on the right side. After trial and error, we finally figured out the correct coordinates in order to align or robots the way we wanted.

Our final idea was to go from a triangle to a rectangle formation using only eight out of the nine robots in the basic shape and one robot in the middle. We used the same world from the previous simulations but changed the initial locations of the robots to start them in an equally-spaced triangular shape. Next, we mapped out where each robot was to travel. Once again, we wanted each robot to move to each spot in the shortest amount of time for efficiency. We therefore began altering previous controllers from our other two simulations. Since we were more familiar with Webots, this formation was much easier and resulted in a successful shape transformation.

Different phases of each shape transformation, from beginning to end, are shown in the *Results* section later in this paper.

IV. What Was Learned

In our beginning efforts, we had to first learn how operate the Webots simulation software. Although difficult to understand at first, once we grasped the concept we were able to create robots from scratch as well as a world to place them in. One of the main things that we learned was how to operate the robot's controller, which is simply the code representing the brain of the robot. We learned how to program each robot by using C-code and were able use its controller to dictate how each robot should behave. When developing the robots we learned how to use its components to create a robot that looked realistic with several sensors. We learned how to add wheels, sensors, body kits, physics, as well as a bounding box to make the robots unique.

In addition to learning so much about the Webots program, we also learned about robotics and simulation. We learned that robotics allows us to develop robots to complete tasks that are potentially harmful to humans or need extreme precision. With this particular project at CReSIS, our aim was to incorporate robots so that human life is not risked due to the harsh polar environment.

With simulation, we learned that robots can be created and tested before use in the field. It allows us to correct deficiencies, improve designs, and validate algorithms within a virtual world. This is useful because it saves time and money and ensures that the final product will be reliable in the field for real-world applications.

V. Results

The following figures show the different shape transitions and transformations from recorded robot team simulations in Webots.

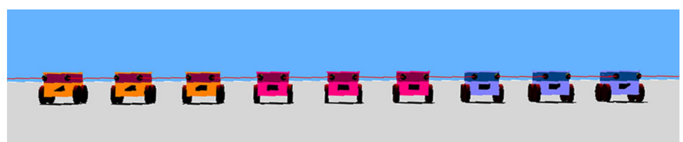

Fig. 4. Beginning of Single Line Transformation

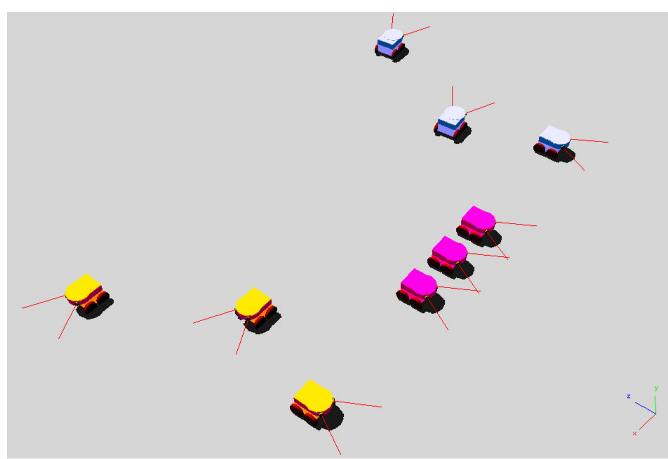

Fig. 5. Middle of Single Line Transformation

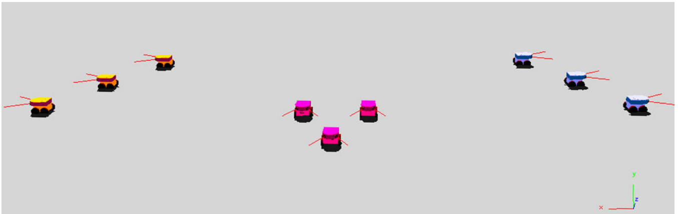

Fig. 6. Completed Single Line Transformation

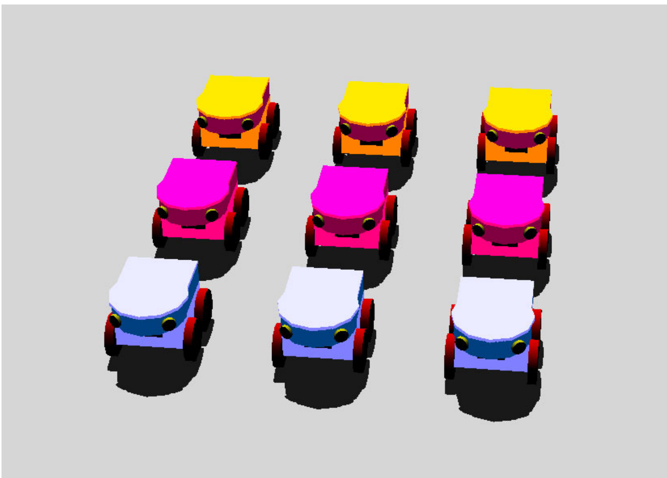

Fig. 7. Beginning of Square to Triangle Transformation

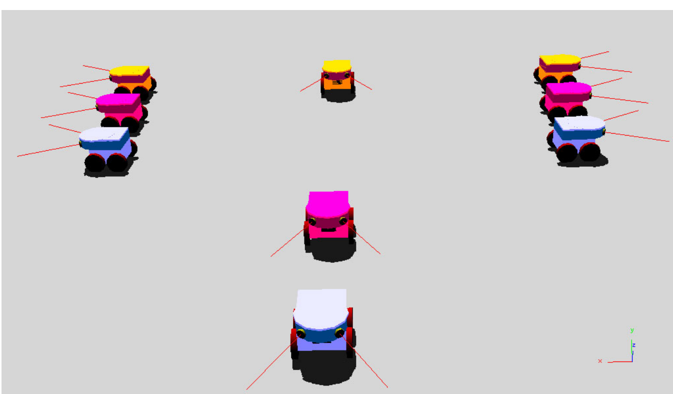

Fig. 8. Middle of Square to Triangle Transformation

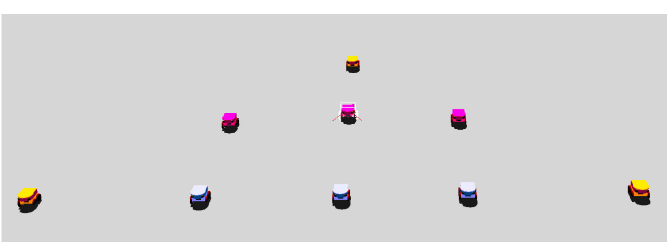

Fig. 9. Completed Square to Triangle Transformation

Fig. 10. Beginning of Triangle to Rectangle Transformation

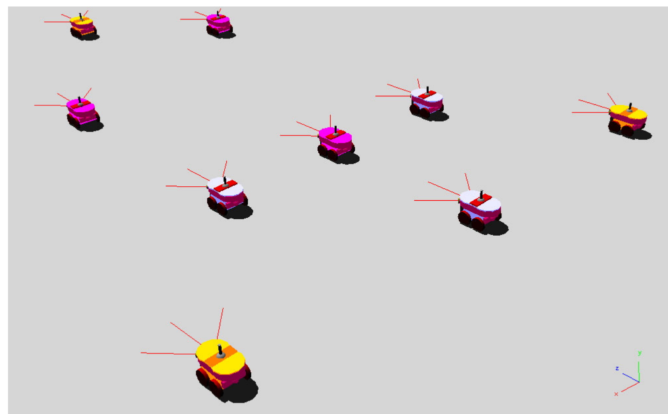

Fig. 11. Middle of Triangle to Rectangle Transformation

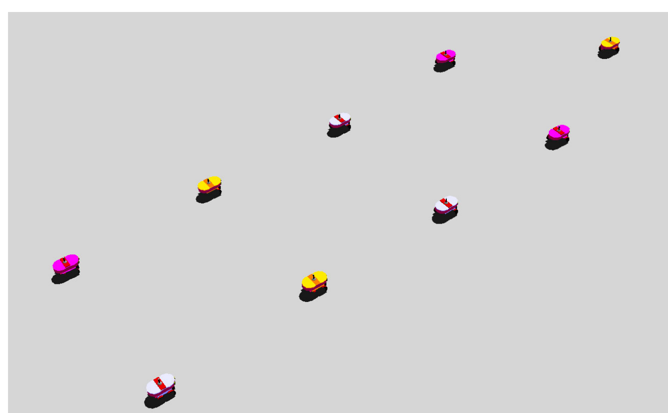

Fig. 12. Completed Triangle to Rectangle Transformation

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