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REU: Improving Straight Line Travel in a Miniature Wheeled Robot

Katie Gessler, Andrew Sabelhaus, Sarah Bergbreiter

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***Abstract*—The TinyTeRP is a miniature robotics platform with modular sensing capabilities. Prior generations of the TinyTeRP have experienced various problems in assembly process, materials selection, and their fundamental design. These problems are addressed by choosing 3D printing as the new manufacturing method and steel wire for the new axle. The TinyTeRP's ability to travel in a straight line using open loop control is studied. After 1.37 m of travel in the x direction, the TinyTeRP was as close as 4.69 cm to or as far as 31.9 cm from the ideal ending position (a straight line), indicating that open loop control is a poor method for controlling a straight line trajectory. Comparing data on the angle of the trajectory collected from position data from the vision table to data collected from the gyroscope indicated that the gyroscope tracks the robot's angle of motion well. Hence, using the gyroscope for closed loop control of the TinyTeRP's motion is possible.**

I. INTRODUCTION

MINIATURE robots, with overall size between 1 mm and 100 mm, have various applications and advantages over larger scale robots. Their small size makes them ideal for applications in swarm, where many robots function together as a group. In addition, their small size allows them to reach and travel in areas where other, larger robots may not be able to. For instance, in a search and rescue situation, small robots would be ideal for climbing over rubble and into small crevices to look for survivors.

Previous research in this area has focused upon developing robust, inexpensive, and easy to assemble robotic platforms for swarm applications. A good example of this research is the Harvard Kilobot, a miniature robot used in swarm applications. This platform was designed with creating a large group of robots in mind; each robot costs approximately $14 and takes five minutes to assemble. This makes assembly of many robots inexpensive and quick [1]. The Alice robot from EPFL is another example of a miniature robotics platform. Like Kilobot, Alice is easy to assemble. This platform is used mainly for sensing applications [2].

Although these robotic platforms have various applications, they also have limitations. The Harvard Kilobot uses stick-slip locomotion from three legs attached to vibration motors, which limits its motion and mobility. In addition, it is not possible to add additional sensors or circuit boards to the Kilobot platform. Alice has improved mobility by using two wheels. However, like Kilobot, it is not simple to add additional sensors or boards.

Fig. 1. TinyTeRP. This is the generation that was developed and tested with this research.

With this in mind, the Tiny Terrestrial Robotic Platform (TinyTeRP) was developed. The TinyTeRP, as shown in Figure 1, is a miniature robotics platform (17 mm x 18 mm x 21 mm) with modular sensing capabilities. The TinyTeRP is inexpensive, costing approximately $40 per robot [3], easy to assemble, and uses wheels for locomotion. A major feature that sets the TinyTeRP apart from other miniature robotic platforms is the use of modular sensing. Many boards can be stacked on top of each other and can communicate through inter-integrated circuit (I^2C) communication.

In this research, we improved the TinyTeRP's straight line travel by developing a final generation of the TinyTeRP, analyzing its straight line trajectory under open loop control, and determining if closed loop control would be possible.

II. TINYTERP DESIGN

A. Features

The major features of the TinyTeRP are shown in Figure 2. The drivetrain and chassis are the main support for the robot, with the circuit boards mounted on them. The drivetrain consists of two DC motors, two axles, and four wheels. Power is transmitted from the motors to the wheels through a gearing system, allowing the robot to travel forward.

The circuit boards are an important feature of the TinyTeRP. Many circuit boards can be stacked on top of each other and can communicate through inter-integrated circuit (I^2C). There are currently two circuit boards that have been implemented on the TinyTeRP – the base board and the inertial sensing board, which are shown in Figures 3 and 4, respectively. The base board (Figure 3) contains a CC2533 microcontroller, which controls the motors, and a radio. The inertial sensing board (Figure 4), which contains an accelerometer, gyroscope, and additional microcontroller, is

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K. Gessler is with the Miniature Robotics Research Experience for Undergraduates (REU) at the University of Maryland, College Park, MD 20740 USA

A. Sabelhaus and S. Bergbreiter are with the Department of Mechanical Engineering, University of Maryland, College Park, MD 20740 USA

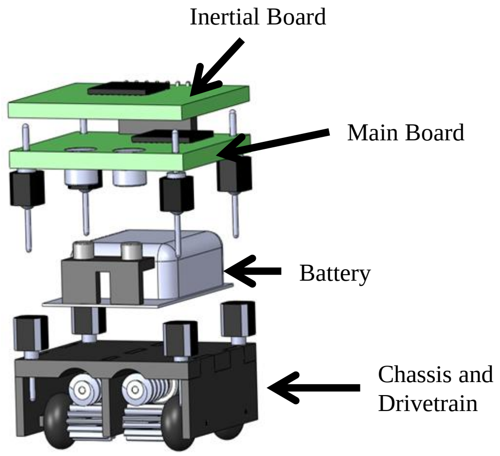

Fig. 2. Major Features of the TinyTeRP.

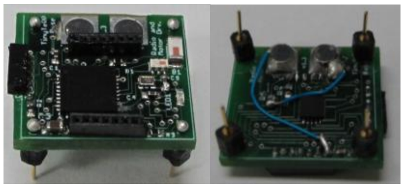

Fig. 3. The base circuit board of the TinyTeRP. The top (left) contains the microcontroller. The bottom (right) contains the radio

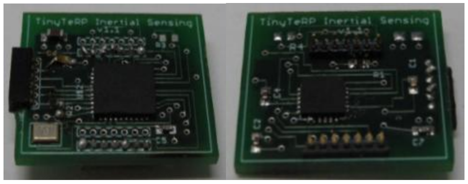

Fig. 4. The inertial sensing board of the TinyTeRP. The top (left) contains a microcontroller. The bottom (right) contains an accelerometer and gyroscope.

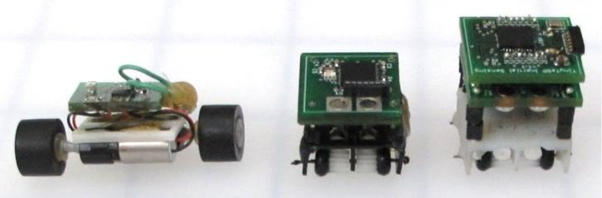

Fig. 5. Prior generations of TinyTeRP. From left to right, first, second, and third generations

mounted vertically on the base board.

The TinyTeRP is powered by a 3.7V, 30 mAh lithium polymer battery. The battery fits between the base board and chassis, as seen in Figure 2, and is connected to the base board through magnets.

B. *Previous Generations*

The TinyTeRP has experienced three generations of designs, all of which are shown in Figure 5. The first generation consisted of a circuit board crudely mounted on top of two DC motors with wheels attached. The second generation improved upon the first by including a laser-cut chassis to hold the drivetrain, which consisted of two DC motors transmitting power to the axle through a gearing system. This generation again had only two wheels. The third and final generation has a 3D printed frame housing the drivetrain – again, two DC motors and a gearing system. This design has two axles and four wheels, improving support.

Prior generations faced various problems in their assembly process, materials selection, and fundamental design. We focused upon improvements to the second generation TinyTeRP. Its laser cut frame made assembly difficult and unreliable. The chassis was made of multiple laser cut pieces, which were glued together by hand. This manufacturing method introduced human error and unreliability; no two chassis would be exactly alike. This unreliability also created problems in the transmission of power; because the tolerances of the chassis were not ideal, the worm gear would not mesh properly with the spur gear and would slip, preventing power from being transmitted to the wheels, and hence preventing the robot from being able to travel forward. This generation also faced problems in its material selection, particularly with the axle material – a carbon fiber rod. Although carbon fiber is a stiff material, with a modulus of elasticity of 230 GPa [4], it created problems by introducing friction. The wire surface is not smooth; it is made of multiple fibers that have been spun together. This rough surface created friction between the axle and the bearing around the spur gear and wheel, preventing them from rotating freely. Fundamental design flaws included that the chassis was made of multiple pieces and that there was only one axle and two wheels.

As part of this research, these issues were addressed to improve the TinyTeRP's chassis design and hence improve straight line travel.

III. CHASSIS DESIGN

A. *Fabrication and Assembly Process*

The first issue to be addressed was the assembly process of the TinyTeRP. As explained above, a laser cut and hand assembled frame in the second generation of the TinyTeRP created many problems for the robot. As a result, it was decided that manufacturing the chassis as one piece would be a better idea in easing manufacturing and eliminating human error. Rapid prototyping through 3D printing was chosen as the new manufacturing method.

This method proved to be advantageous for various reasons. First, the chassis was made as one piece, which eased assembly and eliminated the human error of gluing pieces together. Second, manufacturing of multiple chassis was quick and inexpensive; 25 chassis could be made in 40 minutes for at most $10. Third, reliability and repeatability of manufacturing was improved with this new method. Laser cutting chassis pieces meant that no two chassis would be exactly alike. 3D printing allows for multiple identical chassis to be easily made. This more reliable manufacturing method also improved the tolerances of the chassis and allowed for optimal meshing of the gears. Finally, 3D printing allows for more possibilities in design. Laser cutting allows only for two dimensional features in a part, but 3D printing allows for three dimensional features. For instance, the spacing for the motors to be placed in the 3D printed chassis was semi-cylindrical to better fit their cylindrical shape, rather than rectangular in the laser cut chassis pieces.

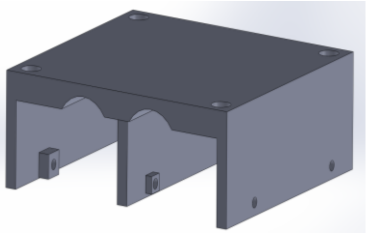

Fig. 6. CAD model of final chassis design. The motors fit perfectly in the semicylindrical section. The square bumpers add extra support for axles and keep the spur gear and wheel in place

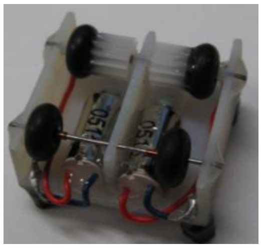

Fig. 7. Final design of drivetrain. This drivetrain has two axles, four wheels, and an optimized gearing system

B. *Materials*

The second issue addressed was the material selection of the axle. As mentioned before, using carbon fiber wire introduced excess friction. To prevent this problem, steel wire was chosen as a replacement material. Like carbon fiber, steel is also a very stiff material, with a modulus of elasticity of 210 GPa [5]. Unlike carbon fiber wire, steel wire has a smooth surface, reducing friction between the axle and the bearing for the spur gear and wheel. In addition, steel wire is an easier material to work with compared to carbon fiber wire. Since carbon fiber wire is made of many twisted fibers, it frays when cut. Steel wire is one solid piece and does not fray.

C. *Final Chassis Design*

The final chassis and drivetrain design are shown in Figures 6 and 7, respectively. This design has features made possible by improvements in manufacturing and materials. The new design is one piece and has two steel wire axles, a cylindrical space for the motors to comfortably sit, and bumpers to provide extra support for the axle and keep the spur gear directly below the worm gear. The tolerances of the new manufacturing method optimized the meshing of the gears, solving a problem faced by the second generation TinyTeRP. The capabilities of 3D printing allowed for new design features, such as the cylindrical space and bumpers, shown in Figure 6.

IV. TESTING

A. *Goal*

Prior generations of the TinyTeRP encountered problems with mobility. Hence, this new generation of the TinyTeRP was tested on its ability to travel in a straight line both without and with sensor feedback from the gyroscope on the inertial sensing board. The results of these tests are used to quantify the straightness of the robot's trajectory and to determine whether the gyroscope feedback should be used in aiding the TinyTeRP in traveling forward in a straight line.

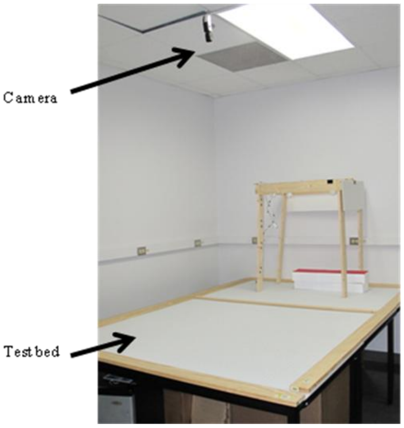

Fig. 8. Vision Table Testing System, with camera and test bed marked.

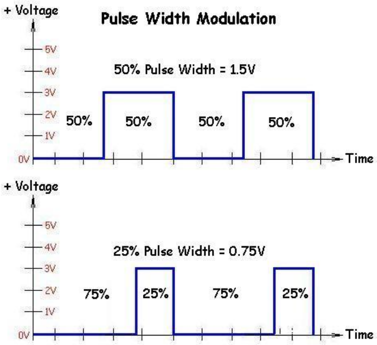

Fig. 9. Pulse Width Modulation. At higher duty cycles (top graph), more voltage is applied. At lower duty cycles (bottom graph), less voltage is applied. [6]

B. *Test Setup*

A vision table system was used for testing. This system consists of a camera mounted above a test bed, on which the robot moves, as seen in Figure 8. As the TinyTeRP moves, the camera tracks its position and records this data along with time. In addition, angular velocity data was collected from the gyroscope. The angle of the TinyTeRP's trajectory was calculated from two different sets of data, position from the vision table and angular velocity from the gyroscope. The angle data calculated from each was later correlated.

The TinyTeRP's motion and speed was controlled by programming the microcontroller on the base circuit board. The microcontroller uses pulse width modulation (PWM) to control motor speed. PWM is a periodic method of controlling voltage. As shown in Figure 7, there are times when voltage is applied and times when no voltage is applied. These times of voltage and no voltage repeat periodically. Changing the duty cycle (the ratio of length of time when voltage is applied to the total time length of the period) changes the motor speed. A shorter duty cycle, one where voltage is applied for a short period of time decreases voltage, and hence motor speed, whereas a longer duty cycle, one where voltage is applied for a long period of time increases voltage and motor speed.

Since the gyroscope was not yet being used along with the microcontroller to control straight line motion, an open loop

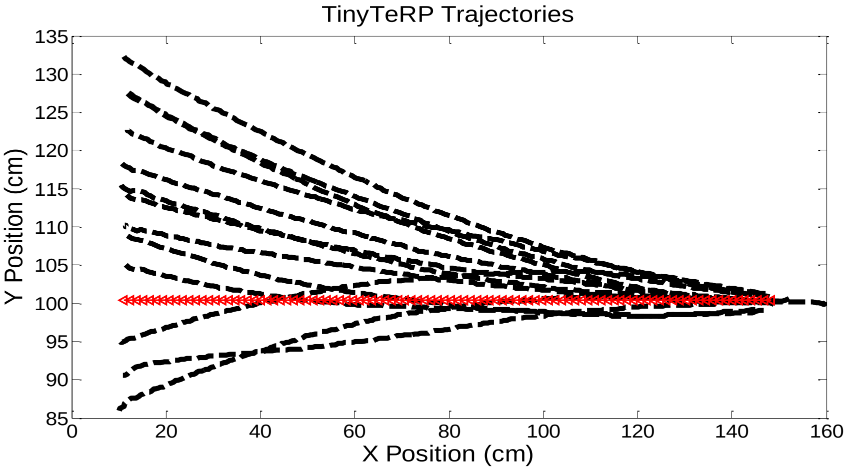

Fig. 10. Multiple trajectories of one TinyTeRP during many trials of testing. The black lines indicate the trajectories one robot took during multiple tests. The red line indicates the ideal, straight line of travel.

control was used to control motor speed and straight trajectory. In this control loop, the user would program a certain duty cycle, observe the results, and change the duty cycle accordingly. For these tests, we used a duty cycle of 45/255.

C. Results

Position and time data was collected for multiple trials where one TinyTeRP started in the same position on the test bed and traveled in the same direction. As indicated in Figure 10, the TinyTeRP's trajectory varied widely from a straight line, and no two trials were exactly the same. For each trial, the TinyTeRP traveled about 1.37 m in the x-direction. Its end position varies from 4.69 cm to 31.95 cm from what would have been a perfectly straight trajectory. This indicates that using open-loop control for the robot's trajectory is a poor method for controlling the TinyTeRP's straight-line motion. Using closed-loop control with the gyroscope could aid in repeatability and reliability in traveling in a straight line.

To test the hypothesis that the gyroscope could create a closed loop control and aid in repeatability in a straight line trajectory, the gyroscope was used during testing to collect data on the TinyTeRP's angular velocity as it traveled across the test bed, again in the negative x direction. The angular velocity data collected from the gyroscope is shown in Figure 11. This angular velocity data was integrated to determine the robot's angle of the robot's path. The angle of

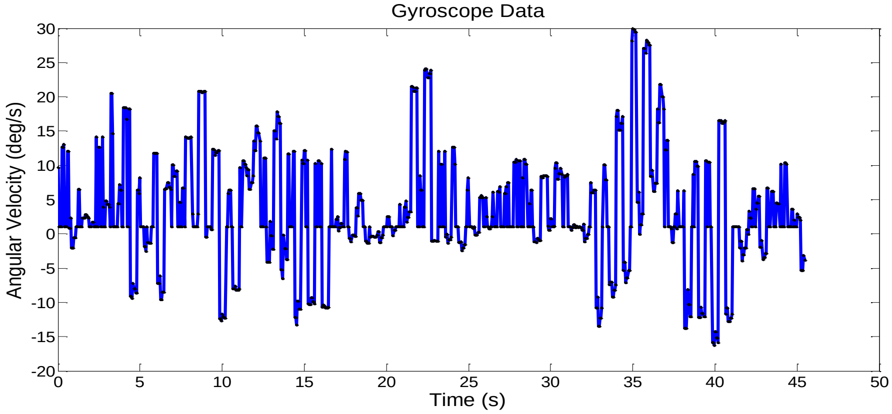

Fig. 11. Angular velocity data collected from gyroscope during testing.

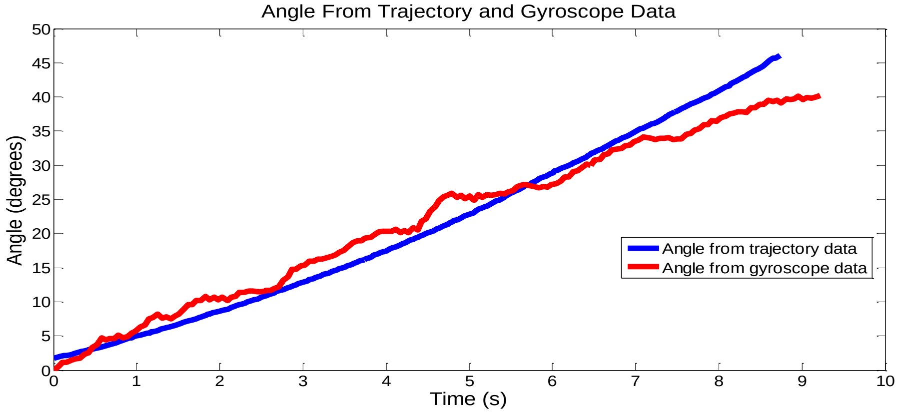

Fig. 12. Angle of motion as calculated from the trajectory data and from the gyroscope data

the TinyTeRP's trajectory was also determined from the trajectory data collected. The two angles were compared for their correlation. As shown in Figure 12, the two angles correlate well together. This indicates that the gyroscope does a good job of tracking the TinyTeRP's angle of motion. Hence, it is possible to use the gyroscope for closed loop control in a straight line trajectory.

V. CONCLUSIONS AND FUTURE WORK

As a result of this work, a third generation of the TinyTeRP was developed and tested on its ability to travel in a straight line trajectory. This new design addresses problems in assembly, materials, and design faced by prior designs. The new manufacturing process of 3D printing improved ease and reliability of assembly and allowed for improved tolerances and new features in design. The steel wire axle reduced friction and improved mobility. Testing of the TinyTeRP's motion revealed that using open loop control for motion is not effective, and it is possible to use the gyroscope to create a closed loop control for forward, straight motion.

Future work involves implementing this closed loop control with the gyroscope and microcontroller to keep the TinyTeRP traveling in a straight line trajectory. The gyroscope can also be used to aid in turns. Finally, many more TinyTeRPs can be built and used to implement and test various swarm algorithms.

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