Intelligent machines and software

DETERMINING HOW TO USE TOUCH, COLOR, AND INFRARED SENSORS TO MEASURE A ROBOT EXPLORER'S ABILITY TO PERFORM SPECIFIC TASKS IN AN OBSTACLE COURSE

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Abstract

While humans can see, smell, hear, touch, and taste to help us understand the world around us, and to navigate and avoid obstacles, robots do not have those abilities. Therefore, robots use different sensors to interpret the environment around them and accomplish tasks such as maneuvering around an array of obstacles (touch), detecting beacons to follow (infrared), or following a path by recognizing different colors. The goal of this project was to explore both the function and efficiency of different sensor attachments on a LEGO Mindstorms EV3 robot prototype. By creating an obstacle course with different tasks and programming commands for the robot to follow, I gathered data on how the color, touch, and infrared sensors function. Reproducibility was measured by the time (in seconds) it took the robot to perform its task. The touch sensor had the best precision, followed by the color and then the infrared sensor. The robot was then tested for completing tasks outside on an icy course. Efficiency was measured by whether or not the robot with sensors could complete the task. The EXPLOR3R prototype with wheels could not function on the slippery icy surface, so I had to change to a tractor type ICEXPLOR3R prototype. My conclusions are that sensors can be used to guide robots through an obstacle course, however, the ability of the sensors to determine efficiency depends on the design of the prototype. Also, sensors can be combined to complete distinct tasks at different stages of the obstacle course. The optimal combinations depend on the environment and task being performed. To improve this project, I would like to learn more about programming and theory in the field of robotics so I can further extend my research into building advanced robots that can tackle real world problems. These simulations will provide data to find the best prototype and combination of different sensors to perform in an unfamiliar environment such as space.

Problem

The use of robotic machinery is becoming more prominent in our everyday lives. Cars now have automatic driving and parking sensors. Robotic machines or “rovers” are designed to explore harsh environments both on Earth and outside our own planet. These all use sensors to accomplish their work. For example, the Mars 2020 NASA Perseverance rover is equipped with 23 cameras, titanium wheels, updated technology, and several sensors (Figure 1) (1). These include items such as air temperature sensors, humidity sensors, pressure sensors, radiation dust sensors, and many more (1). Scientists rely on sensors to detect environmental factors and identify possible problematic obstacles they will face as they explore unknown territories. As more exploration robots are being developed, scientists must find the optimal combinations of sensors and consider aspects such as cost, durability, and functionality as the question arises of which sensor, or sensor combinations are the most efficient and useful for the conducting research. In this project, I will design prototype robots and obstacles to explore how different sensors work.

Research Questions

1. What is the best prototype robot explorer design to examine unknown terrain?
2. Can we design an obstacle course that will examine how the sensors work in this prototype robot?
3. How do the sensors affect robot efficiency?
4. How do these prototype + sensor robots work under real world obstacles?

Hypothesis

1. Based on my last project, and the different prototype Mars robot explorers, I hypothesize that the EXPLOR3R prototype with rubber wheels will be the most efficient on the obstacle course.
2. The obstacle course will test each sensor individually to define how it works.
3. The sensors will have different response times and sensitivity.
4. The prototype + sensors will work the same on all the obstacle courses.

Rationale

For this project, I am testing sensors such as color, touch, and infrared to determine how they function on a LEGO EV3 robot. I built, programmed, and ran tests with each attachment to see how each sensor performed a specific task.

The first hypothesis looks at robot design. What is the best design to tackle the obstacle course? As each sensor is tested, the precision should remain the same. Although each sensor is performing a different task, the concept of efficiency is being measured as the ability to complete the task. As the touch sensor undergoes its task, the reaction time will be faster as only a touch is needed for it to be activated. As each sensor specific task is performed, calculations are needed to specify the function of each attachment. For instance, calculating angle measures with the infrared sensor's corresponding programming of -25, 0, and 15 to measure angles of 180, 45, and 90 degrees.

This research is scientifically important because as of yet, we have been unable to send a human to another planet, such as our neighbor, Mars. So in our place, we send rovers to gather information and collect data to report back information to us so that we can analyze it back on Earth. As these rovers are being developed, they are assigned a variety of tasks to conduct, such as collecting terrestrial samples, measuring oxygen levels, or recognizing radiation or dust around it. This project will help researchers to build the right prototype explorer and decide the optimal combination of touch, color, and infrared sensors to carry out different missions.

Background

The iterative design method raises the question of efficiency when finding solutions for greater exploration. Many engineers and scientists are discovering new ways to build intelligent robots for modern challenges. Robots are needed for a variety of tasks, from an automatic vacuum cleaner to rescuing a person in dangerous circumstances, such as in rubble after an earthquake. As robotic engineering becomes more advanced, new tools are needed to improve a robot's functionality and usability in all fields, whether it be something simple such as a vacuum cleaner or a space rover, like that of the Curiosity or Perseverance NASA rovers. It is then that scientists and engineers turn to the use of sensors.

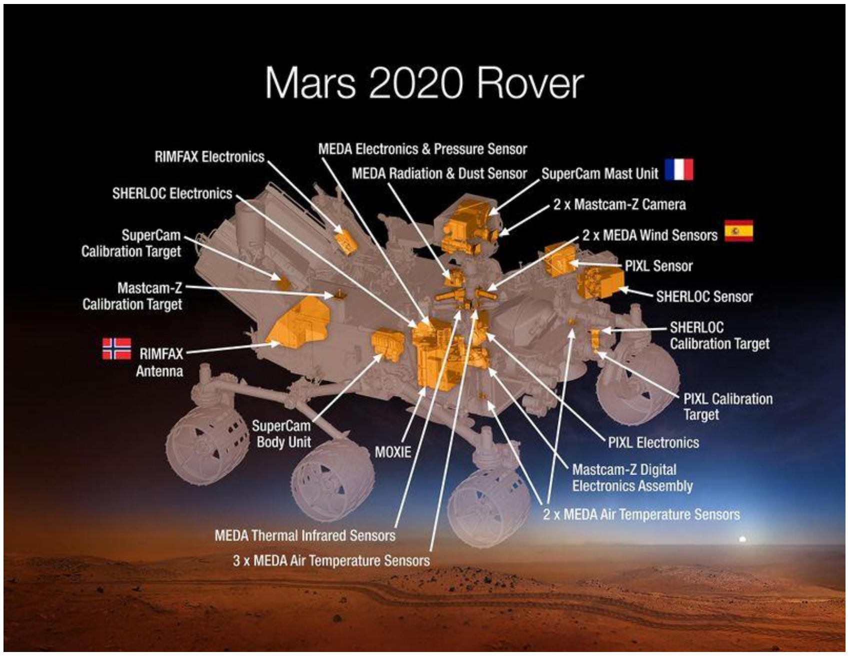


Figure 1: Sensors on the Mars 2020 Rover

The Mars 2020 Perseverance NASA rover made its successful touchdown on February 18th, 2021. This 2.7-billion-dollar project (2) was a breakthrough not only for scientists at NASA, but for all of us around the world, as we were exposed to never-before-seen up close pictures of the Red Planet's surface.

Figure 2: One of the first pictures of the planet Mars taken by the Perseverance Explorer

Here on Earth, we don't know what lies on our neighboring planets, much less the vast expanse of outer space. Perseverance's trajectory was a journey that lasted around 7 months to reach Mars (2). As the time approached for Perseverance to land, the control room couldn't do much to assist the robot around a sea of debris, as it was almost 325.27 million kilometers away (3). It was at this time that the rover relied on its sensors installed by the scientists to land and deploy safely, which fortunately, it did. Even before that when the rover entered the atmosphere, thermocouples, heat flux sensors and pressure transducers were activated to provide feedback information that would prevent a complete derailing of a long journey of exploration (1).

Perseverance was put straight to work, analyzing atmospheric conditions, terrestrial samples, and even scanning for signs of life. These tests were sent back to Earth for scientists to find out more and gain a better understanding of the planet.

Exploratory robots use color sensors for moving along a line and detecting shadows, so as not to fall into craters. They use touch sensors for detecting rocks and boulders and moving around them, and infrared sensors to follow a beacon of light (go back to the base at night, get out of a cave) and to accept remote instructions. Upon landing, the robot has to function solo - using only sensors + measurements + programming -until it can get to a specific location where it can be controlled remotely. First the robot is relying on info from the sensors and the programming alone, then it relies on being able to detect and use the infrared signal for remote control instructions. My experiments aim to study how this works.

Mars has been an ambition for engineers around the world since the beginning of the space race, and it only continues to grow as we gain more knowledge on the new planet. The focus of this project was to focus on the importance of sensors in the functional tasks of a robot explorer. Without sensors, basically no exploration would be possible. As there are different conditions on Mars and Earth, sensors are essential to gain a larger understanding of the new terrain.

Materials

Large posterboard	4 cm barrier
LEGO EV3 Robotics kit	Stopwatch
Computer with Mindstorms EV3 App	Ruler
Index cards with red, yellow, and blue colored boxes (3x5 centimeters)	Protractor
LEGO Mindstorms EV3 Discovery Book	Data log notebook

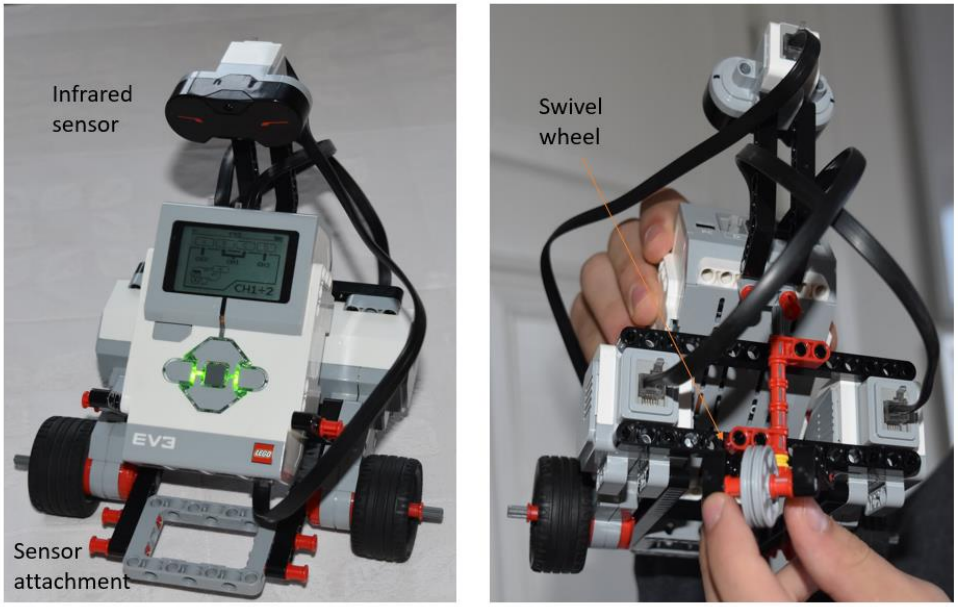
Methods

The robot prototype was assembled using the instructions in the LEGO Mindstorms EV3 Discovery book. Prototype models tested were developed through iterative design based on last year’s Unge Forskere project.

TRACK3R GRIPP3R EV3RSTORM

Robot designs built with EV3 Lego Robotics Kit – NZ Unge Forskere 2021

Figure 3: Previous project’s robotic design protoypes



a. EXPLOR3R Prototype b. EXPLOR3R Prototype back view

Figure 4: Improved EXPLOR3R prototype with features such as elevated SmartBrick and a stabilization wheel in the back

To carry out this experiment, the Mindstorms EV3 App was used. I used the app which I downloaded off the LEGO Mindstorms website. I had to modify the program to give specific instructions for each sensor. They are stated as follows:

Color Sensor Test: The robot began at the starting line and ran a forward program until it recognized a color. The different colors gave different commands, which are stated above.

Color Sensor	Yellow spot	Red spot	Blue spot
	- Spin 360 degrees	- Reverse 3 rotations	- Pause and continue for 3 rotations.

Infrared Sensor Test: The robot was given a command to move from point A to point B. The beacon was placed at different degree points to compare time taken for each position. Point A was the same, the starting point, but point B varied as the angle measures fluctuated. The distance between the beacon and the endpoint was the same for each angle, however.

Infrared Sensor	- -25 (180 degrees)	- 0 (90 degrees)	- 15 (45 degrees)

The robot was given a program that ran a forward motion until the touch sensor was triggered.

Touch Sensor	Contact with a 1.5-inch barrier (4 cm), reverse 3 rotations, turn 90 degrees, and continue forward 3 rotations.

Programming the sensors required specific instructions that varied for each procedure. For instance, a yellow command icon was used for the color sensor to spin 360 degrees when it detected yellow. Similarly, the touch sensor was instructed to reverse 3 rotations (a rotation is a 360-degree revolution of the motors), turn 90 degrees, and continue forward. The infrared sensor relied on a beacon transmission, dependent on calculating angles, so a different command was used to notify the robot of its task.

After the programming was complete and transmitted via Bluetooth, the robot was placed at the start of the course. I made sure to mark the posterboard, so I knew I was beginning at the correct location each time. I ran the trials for the color sensor first.

The stopwatch began when the program was initiated by pressing the button in the middle of the SmartBrick. As the robot commenced, the time was monitored and stopped only when the robot had completed its programming completely, coming to a full stop.

The color sensor was then removed and replaced with the other attachments.

This process was repeated 10 times for each color and each program, then 10 times for the touch and infrared programs as well.

The data was recorded in the notebook each time.

After the data was written in the notebook, it was transcribed to Microsoft Excel and analyzed. Graphs were also created using Excel. The averages and standard deviation were calculated from the data using Excel functions.

All elements of the final report including text, graphs, tables, and pictures were created by the researcher.

Risks: Some components of the LEGO EV3 kit are a choking hazard for small children and can be considered hazardous.

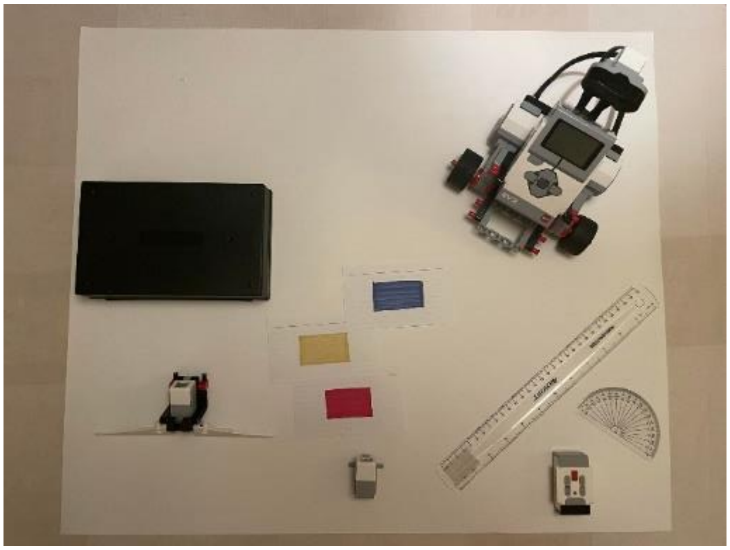


Figure 5: Improved robotic design with sensors and obstacles displayed

Variables

Independent Variable:

The independent variable in this experiment is the sensors used. The functionality of the robot varies based on the type of sensor used.

Another independent variable is the materials used on the obstacle course, the barrier, index cards, angle markings and distance between points in regard to the infrared sensor.

Dependent Variable:

The dependent variable is the amount of time it takes for the robot to reach its end goal. This will be measured in units of seconds. As the independent variable, the robot's sensors, changes, so will the time on the course.

The time to complete a task will also be affected by the programming the robot is designated according to its sensor.

Controlled Conditions:

To keep the experiment consistent and valid and to be able to compare sensor efficiency, a few aspects needed to be controlled to ensure validity. As mentioned in the method, the robotic design, the EXPLOR3R, remained the same the entire experiment. Because of this, the same EV3 set was used this entire experiment, so as not to let issues such as battery life or age be a contributing factor.

Each program was created using the same software and same computer. It was sent to the robot the same way each time as well.

No other sensors were used as this was a closed experiment that tested only 3 different types of attachments. The sensors were attached through the same port of the SmartBrick with the same wire.

The outdoor course challenge required that I modify the EXPLOR3R robot by changing the wheels to tractor type gripper wheels ICEXPLOR3R. The same programming was used as the indoor course to evaluate the sensors.

Results

Figure 6: EXPLOR3R with (a) touch, (b) color, and (c) infrared sensors

Figure 7: Color sensor trials with different colored index cards detected by robot.

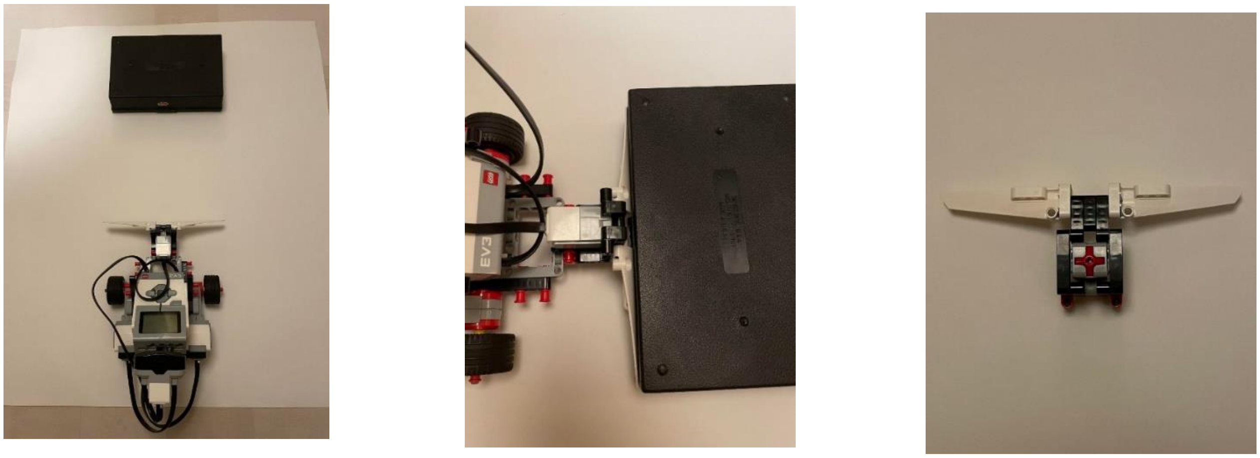


Figure 8: Touch sensor trials(a) with 4 cm barrier with contact (b). Touch sensor is shown with added bumpers (c).

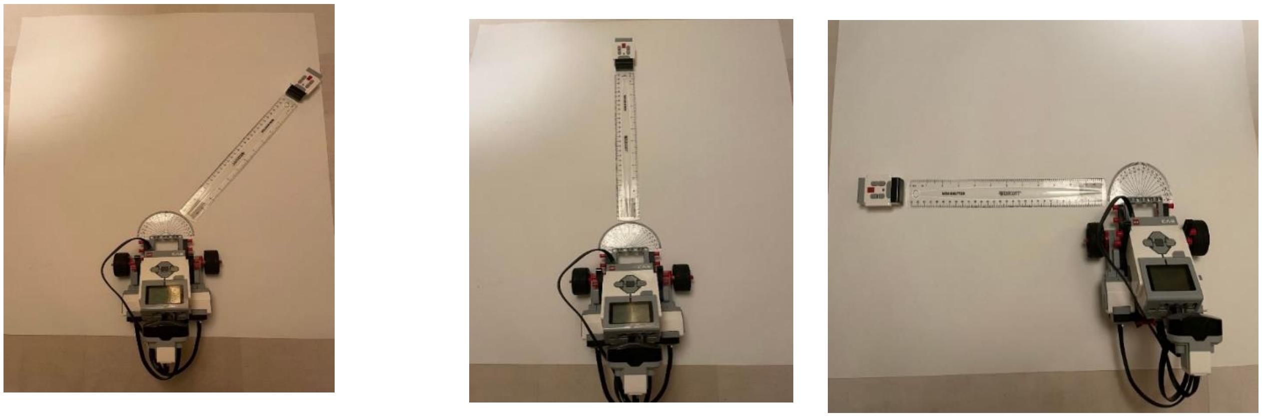
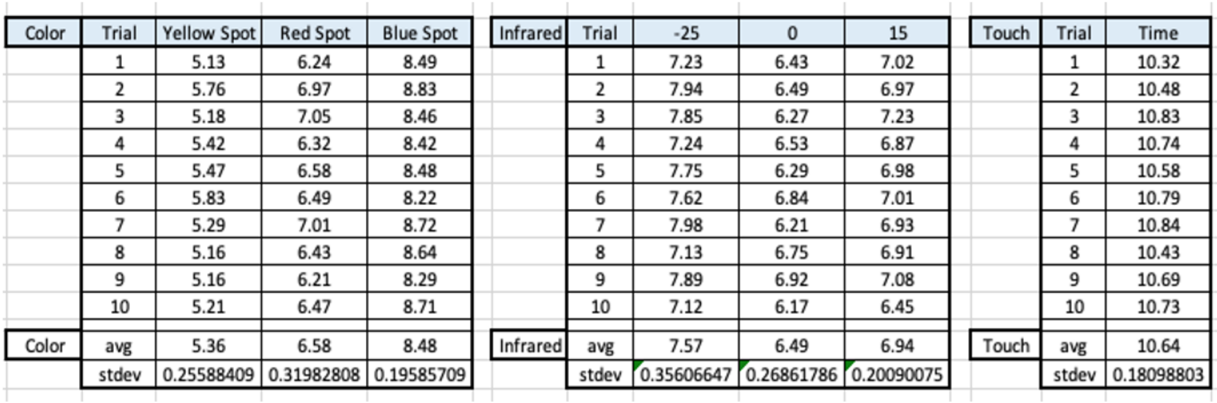


Figure 9: Infrared sensors with measurements of 15 (a), 0 (b) and -25 (c). These angles correspond to 45, 90, and 180 degrees



Color	Trial	Yellow Spot	Red Spot	Blue Spot
	1	5.13	6.24	8.49
	2	5.76	6.97	8.83
	3	5.18	7.05	8.46
	4	5.42	6.32	8.42
	5	5.47	6.58	8.48
	6	5.83	6.49	8.22
	7	5.29	7.01	8.72
	8	5.16	6.43	8.64
	9	5.16	6.21	8.29
	10	5.21	6.47	8.71
Color	avg	5.36	6.58	8.48
	stdev	0.25588409	0.31982808	0.19585709

a. Color sensor

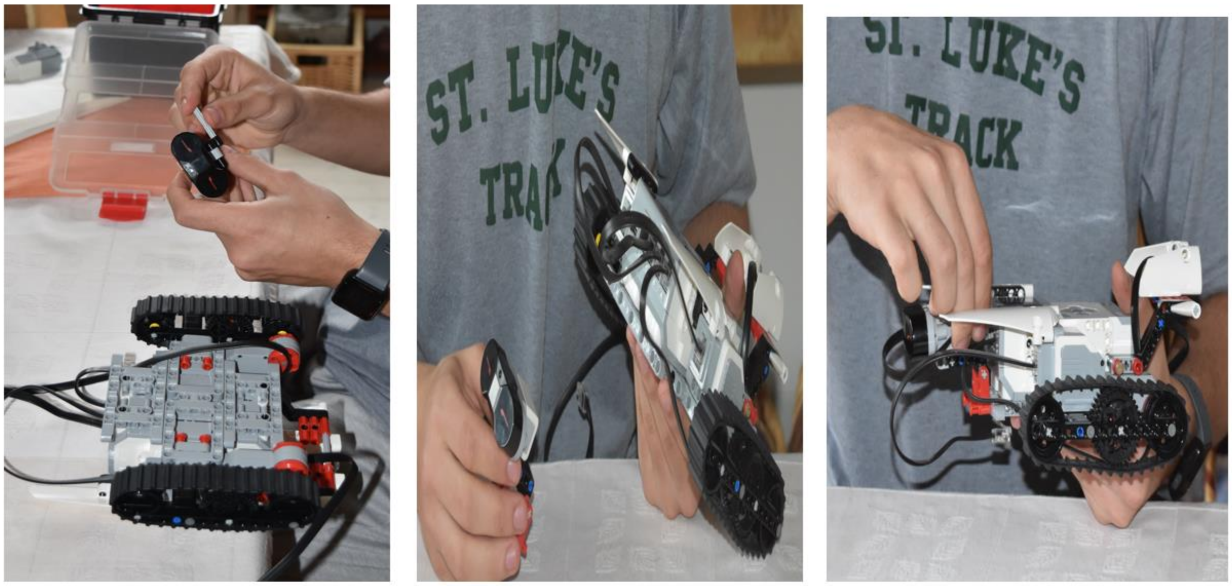
Infrared	Trial	-25	0	15
	1	7.23	6.43	7.02
	2	7.94	6.49	6.97
	3	7.85	6.27	7.23
	4	7.24	6.53	6.87
	5	7.75	6.29	6.98
	6	7.62	6.84	7.01
	7	7.98	6.21	6.93
	8	7.13	6.75	6.91
	9	7.89	6.92	7.08
	10	7.12	6.17	6.45
Infrared	avg	7.57	6.49	6.94
	stdev	0.35606647	0.26861786	0.20090075

b. Infrared sensor

Touch	Trial	Time
	1	10.32
	2	10.48
	3	10.83
	4	10.74
	5	10.58
	6	10.79
	7	10.84
	8	10.43
	9	10.69
	10	10.73
Touch	avg	10.64
	stdev	0.18098803

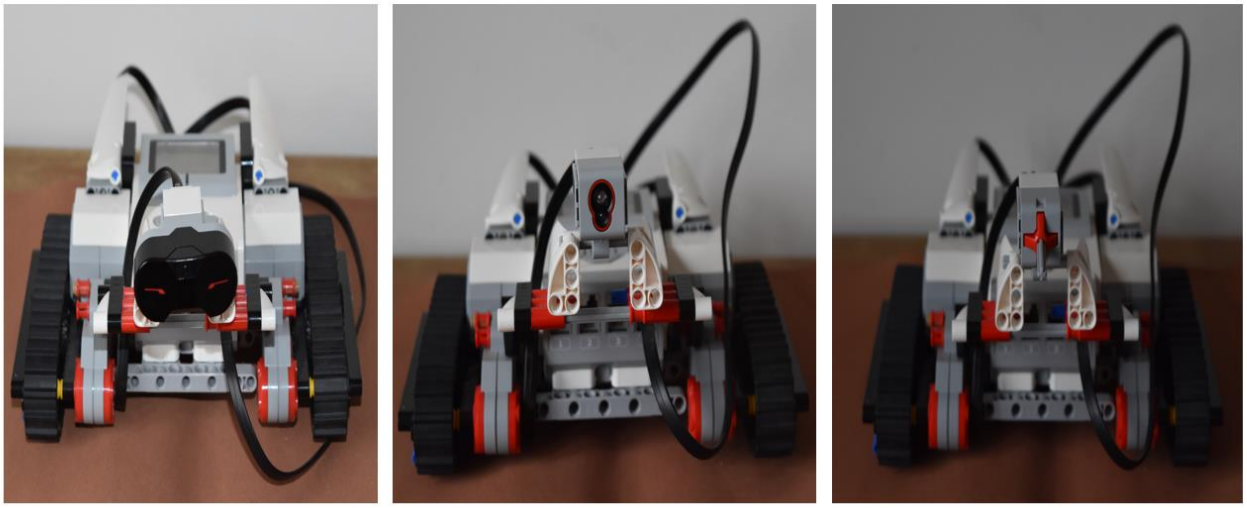
c. Touch sensor

Table 1: Data analysis from the trials conducted with averages and standard deviations included



Building the ICEXPLOR3R Prototype

Figure 10: Construction of the ICEXPLOR3R Protoypes



a. ICEXPLOR3R Prototype
with infrared sensor

b. ICEXPLOR3R Prototype
with color sensor

c. ICEXPLOR3R Prototype
with touch sensor

Figure 11:ICEXPLOR3R completed prototypes with sensors attached

Preparing the outdoor course for the ICEXPLOR3R Prototype

Figure 12: Testing and recording data from the outdoor experiment of the ICEXPLOR3R

Evaluation of Results

I tested the three different sensors by programming different tasks for each attachment. The results showed that the time varied depending on what task the robot was given. For example, the touch sensor had an average time of 10.64 seconds when conducting its procedure, meanwhile the infrared and color trials had much shorter times. For the color sensor, the yellow spot averaged 5.36 seconds, the red 6.58, and the blue 8.48. For the infrared, the -25 measure averaged 7.57 seconds, 6.49 for measure 0, and 6.94 for measure 15.

Since the tasks were different, we can only determine the precision within one data group. With this data we can determine the standard deviation of the different groups, as shown in Figure

The data supports hypothesis 1 for the indoor course only. Hypothesis 4 was not supported, because the EXPLOR3R prototype could not perform on the outdoor course at all. The data supports both Hypothesis 2 and 3.

The results from the real world course mirrored the indoor course, with some differences. The EXPLOR3R robot could not complete any task because the wheels would slip on the ice and the robot would stop. I changed the wheels to the tractor, (ICEXPLOR3R prototype) and ran the sensor tests with different obstacles. Similar results were obtained, so the programming worked the same for the inside and outside conditions.

Improvements and Extensions

Many prototype robots have been developed to explore outer space by using an iterative design method that identifies problems and improves previous versions. . An issue I came across in my previous project was the SmartBrick being too close to the ground and affecting the robot’s mobility. To resolve this, I built a design that had the SmartBrick off the ground so as it would not affect the robot’s movement.

The EXPLOR3R prototype robot integrates data from my project from last year and improves previous designs by using rubber wheels and lifting the brick off the ground. This prototype was then further modified with track wheels for icy conditions to become ICEXPLOR3R

I had a little trouble programming the robot itself, as the software had updated and the interface had completely changed to a sleeker, newer design that took some time getting used to.

As tests on the infrared sensor included simple angular measures such as 180, 90, and 45 degrees, the project could be expanded by calculating elements such as the sine, cosine, and tangent of the angles created with the resulting triangles. More angles could even be incorporated as the project was expanded onto new horizons.

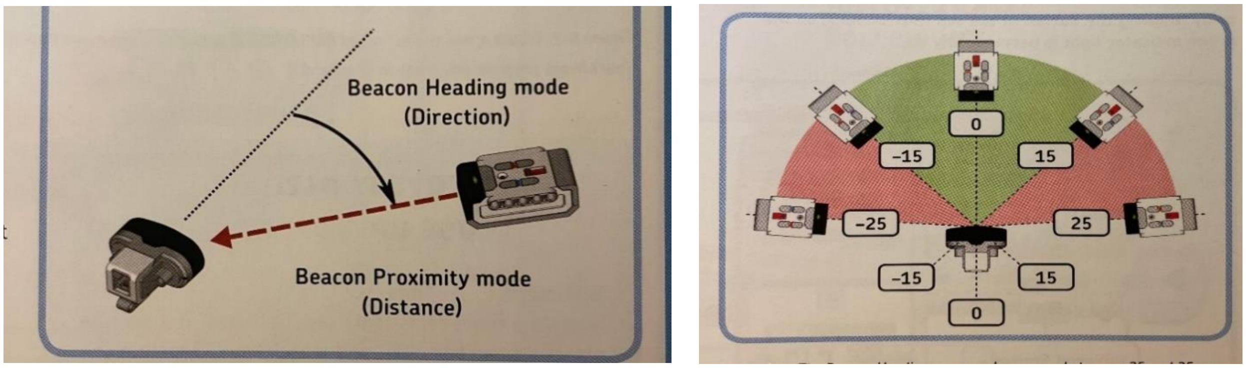


Figure 13: Explanation of beacon function as well as infrared capabilities.

While testing three sensors gives an in-depth analysis to those particular areas, dozens of sensors are used in large scale projects so that researchers can gain a broader understanding of the terrain around them, such as on the Red Planet. Different movements, more sensors, different terrains, and many other factors could be incorporated into future experiments.

While my project could benefit space research, that is not my only area of focus. NASA is already deploying marine rovers to explore the ocean depths. With most of the ocean not even explored by humankind, unknown caves, animals, and much more lie underwater in depths we haven't even began to explore.

At NASA's Jet Propulsion Laboratory in California, an underwater rover called BRUIE is being tested for future missions on icy moons (5). The Buoyant Rover for Under-Ice Exploration is being tested in the Antarctic Ocean to later be deployed as an exploratory device in what scientists believe to be frozen lunar oceans on other planet's moons, such as Jupiter's moon Europa and Saturn's Enceladus (5). Uncovering a discovery like water on another planet could be found through this prototype, pictured below.

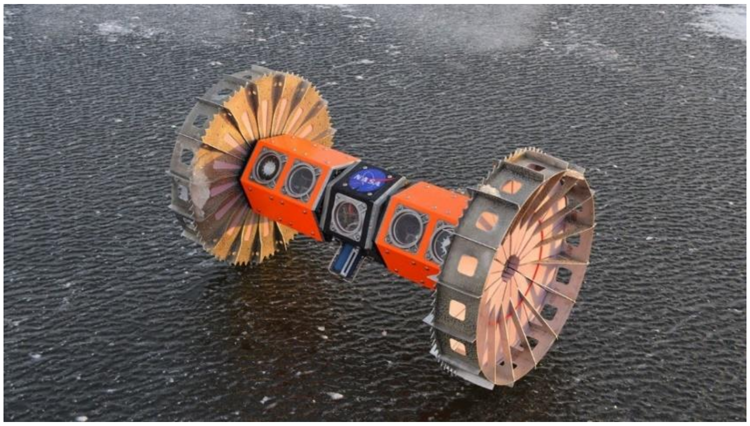


Figure 14: The BRUIE underwater exploration rover.

These types of projects can also directly benefit humans in dire situations. For example, a robot sent in to rescue survivors of a natural disaster can use touch sensors to feel around debris and heat or vital sensors to sense for life around it. Infrared sensors can provide distanced communication when programming is not possible, such as in the case of NOAA's Undersea Robot Deep Discoverer (6). Known as D2, the robot records high quality footage and images almost 4 miles down in the ocean depths. The robot also can gather samples of marine life and geology for future studies (6).

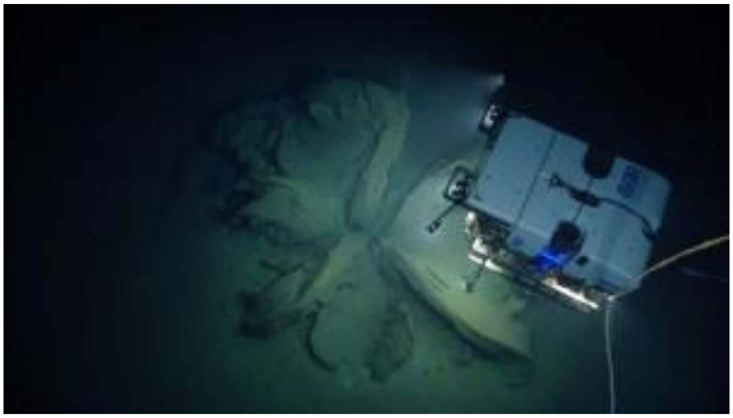


Figure 15: D2 Robot exploring remanent asphalt volcanoes deposited on the ocean floor (6).

Sensors can even be integrated into schooling as children begin to communicate with robotic technology and use face recognition sensors as well as touch with activities in the learning environment. Not only do sensors benefit scientists, but future generations as well.

Conclusions

Finding the optimal combination of touch, color and infrared sensors to navigate a robot explorer through simulated space-like conditions

The data shows that each sensor performed different tasks to measure its individual capabilities. The most precise sensor was found to be the touch sensor. The conclusion could be drawn that while the touch sensor is not good for recognizing whether a spot is yellow, red, or blue, it is good at responding to an obstacle placed in front of the robot. Likewise, the color sensor cannot detect infrared waves through a medium, but it could recognize the different color shades in soil to follow a path. When the Mars Rover was initially deployed, it relied on sensors and programming until it could be accessed by remote control. So in this experiment, the color and touch sensors could be pre-programmed to bring the EXPLOR3R to a place on the course where the infrared sensor can detect a signal.

The prototype with rubber wheels was not the best design for the real world challenge on ice. The robot was given a program that ran a forward motion until the touch sensor was triggered. The ability to complete tasks was independent of the sensors. The wheels spun and could not grip the ice. The change to the ICEXPLOR3R design with gripper tractor wheels allowed for the sensor experiments to continue on ice. Since the measurements were all similar to the ones obtained indoors, this means that the icy conditions did not affect the functions that were controlled by the programming. It was only the ability of the robot to move in the external environment that was affected.

Upon further investigation, most of these sensors are used in real life robots to maximize efficiency and capability of the robot. Function is measured on several fronts rather than one at a time, and a combination of sensors is the best solution for exploring a foreign environment. The results of this project could be used to find optimal design and combinations of sensors for unknown terrain exploration.

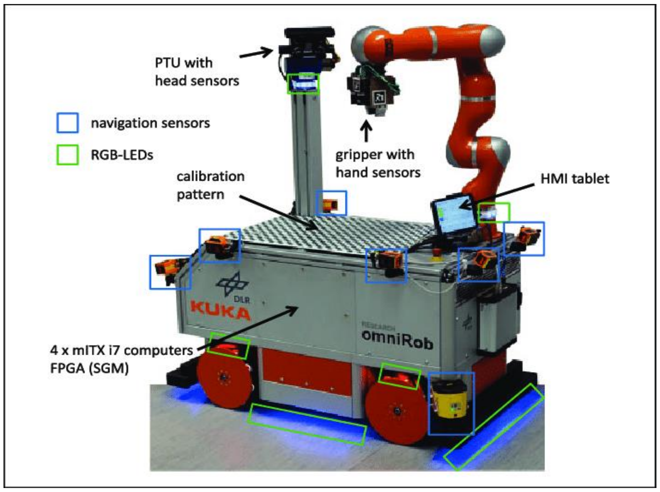


Figure 16: KUKA exploration robot with sensors highlighted to show capabilities. KUKA is developed by the European Space Agency with the main goal of combining the elements of the GNC laboratory that simulate the EDL or Rendezvous trajectory of the spacecraft (4).

Future Studies

I grew up in Orlando, Florida, only 45 minutes away from the Kennedy Space Center. A large part of my childhood was spent going to see the shuttle and rocket launches. Just last year I attended the European Space Camp (virtually) and was exposed to more ideas and became more interested in robotics research on planets beyond our own.

Engineers, scientists, and researchers must consider a wide variety of mathematical and computational problems when creating a durable machine that will serve as a long-term solution for gathering data. This experiment touched on applications such as angle measurements and calculations regarding programming and coding, but I look forward to learning more about robotics concepts such as kinematics and python coding to go more deeply into this subject.

To improve this project, I would like to learn more about the field of robotics so I can further extend my research and build advanced robots that can tackle more complex obstacle courses. For example, to continue this research project, I'd like to conduct this experiment in a completely different environment where inclines, moving obstacles, and more attachments are present. For detailed analysis, more trials can be conducted and perhaps more extensive programming for different prototype models. The independent variable could be changed to accommodate different sensor combinations as well. Having a challenging course where different robots could be put to the test and proving one prototype's superiority over the other could also be interesting to observe. These simulations will provide data to find the best combination of different sensors to aid the robot's ability to perform in an unfamiliar environment such as space.

Ultimately, I would like to be part of a team that builds a robot that will function in a real-world application and solve a real-world problem.

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