SEMI-AUTONOMOUS RESCUE TEAM

Team Description Materials 2022

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Semi-Autonomous Rescue Team

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Logistical Information

Team Name	Semi-Autonomous Rescue Team (S.A.R.T.)
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1. Introduction

The Semi-Autonomous Rescue Team (herein known as the S.A.R.T.) is a group of STEM enthusiasts originally formed in early 2015 with the intent of developing and creating a robot capable of competing in the 2016 Rapidly Manufactured Rescue Competition (RMRC) at RoboCup in Leipzig, Germany.

2. Reflection on experience at RoboCup 2021

S.A.R.T. participated in the RMRC at RoboCup remotely in 2021. S.A.R.T. was tasked with creating a robot capable of travelling through a small course filled with obstacles. Points were awarded on how many times the robot could go back and forth in the course within a specific time limit. The robot was controlled remotely by a driver who was only able to see through cameras secured to the robot making the task even more challenging. Since S.A.R.T. was competing remotely in 2021, alternate cameras had to be set up to record each of the runs for the RMRC. The teleoperator was not allowed to view these cameras during competition runs, the sole purpose of these cameras were to record the robot from a birds-eye view for submission. The team also was required to record and submit oral presentations that would have occurred at the event had it been held in person in addition to the recordings of the robot's competition runs. The videos and presentations S.A.R.T. recorded was a replacement for the TDM. Instead of writing up a document, we presented the outcomes and the work we did all in one video presented by some of the team members. We worked tirelessly day and night to achieve our projected goals and due to our hard work, we successfully reaped the rewards. S.A.R.T. came out with a total of 4 significant recognitions in the RMRC. We were awarded with our robot having the best mobility and manoeuvring in the competition. Our robot was able to travel the cause with ease and the turning ability was superb. This was only one accolade we received though. Another feature of the robot the team was praised for was the exploration and mobile sensing of the robot. One final aspect of our submission we were rewarded for was our video presentation. S.A.R.T. had the most thorough and well-presented video in the competition. Although we were rewarded with these three separate accolades, there was one prize that was won which holds far greater importance. The team was rewarded with the Open Source and Innovation award. This specific award is granted with a trophy and is the most prestigious and sought-after prize in the RMRC. Our hard work and tireless nights were paid off as S.A.R.T. achieved our goals and more, and the team will be looking to follow up on that impressive performance in 2022 where we will compete remotely once again.

3. System Description

Hardware

The Bender Mark 2 is vastly different from its predecessor. It was introduced in May 2022, and has seen a number of changes and modifications added onto it, this results in it being vastly different from Bender Mark 1. One of the most significant changes we made when introducing this design is the addition of a manipulator arm. This arm (Figure 1) will allow us to compete in a higher competition level. The arm was designed in Fusion 360 and the main parts will be manufactured with 3D printing. To connect the different sections of the arm, carbon fibre rods will be used. The arm will be able to fold over itself as seen in Figure 2 to create a much easier and efficient way to move it out of the way.

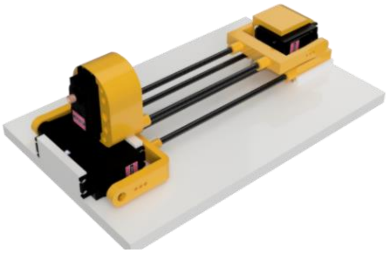

Figure 1 – Render of Arm

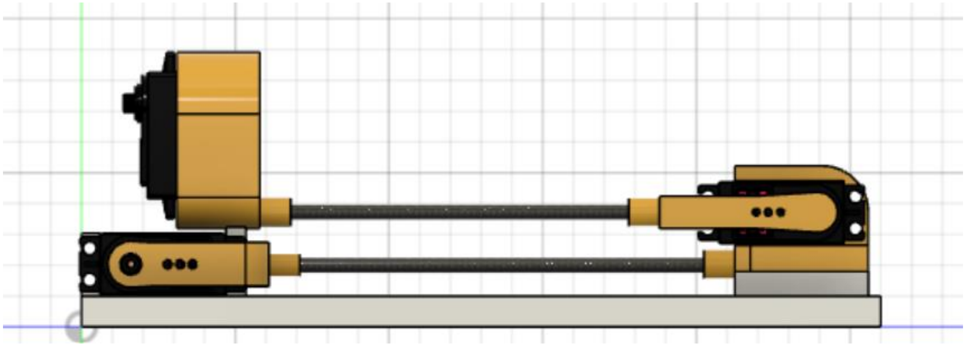

Figure 2 – Render of Arm (Side View)

S.A.R.T. also made changes to the chassis of the robot. It had a whole redesign other than the tracks. We kept the same wheels and tracks since that worked effectively on the Bender Mark 1. The first section we decided to change was the material of the robot. Mark 1 was made out of Aluminium and the lid being laser cut. We moved away from that and decided to crate Mark 2 from 3D print and acrylic. The reason for this was because it was easier to design and create the chassis if it was 3D printed. We were able to design the chassis using Fusion 360 and directly export the file and 3D print it making the whole process much more efficient. The acrylic was used for the bottom and the top of Mark 2. This material was much easier to acquire and cut to the desired size. Moving away from the material of the chassis, the robot was also designed to be much narrower. This was done to fit the arm on top of the robot without causing any issues of the robot being too tall so the arm would get caught on things. We also had the front and back of the robot be much more rounded so that when it is travelling over various obstacles the Chassis won't restrict its ability to get over the obstacles. Finally, we are also using much stronger motors in Mark 2 so we can travel over more difficult obstacles since we have more torque. The comparison the Mark 1 and Mark can be seen in Figure 3.

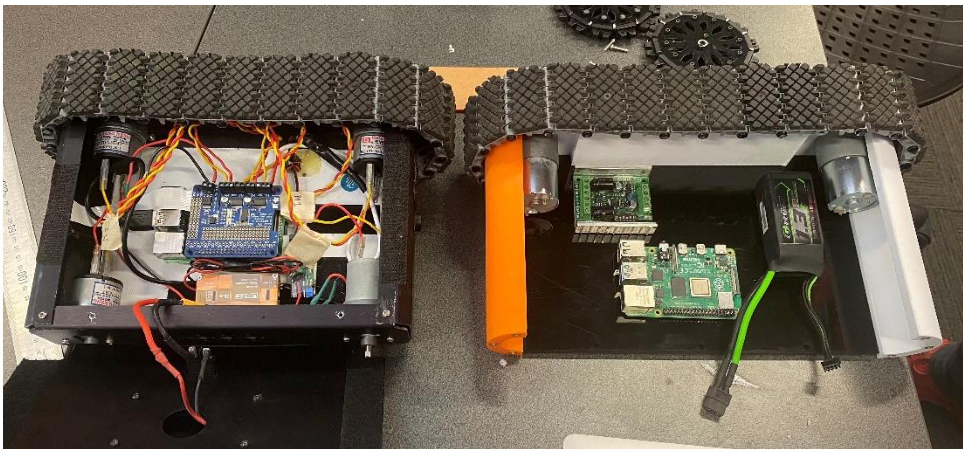

Figure 3 – Comparison of Bender Mark 1 (Left) and Mark 2 (Right)

S.A.R.T. wanted to change their way of controlling the robot. We are still using Sights, which is the same software used on previous robots including the Mark 1 but changes needed to be made so we can control the arm from the same keyboard. We are still using the arrow keys or WASD to move the robot, but we have now implemented the number pad to control the arm. Besides from adding new features we also changed to using a Sabertooth motor controller and a servo Raspberry Pi hat so we can control the motors from the robot and the servos for the arm all in the one place. The Sabertooth motor controller uses PWM or 'Pulse Width modulation' which regulates the speed of DC motors. When we use a PWM pin to pulse, we are pulsing a voltage on or off at a certain frequency which is denoted by 1 on the period of the voltage wave. Interfacing the two proved to be a challenge due to the logic level control system operated at. The sabretooth operates at a 5V logic level while the Pi operates at 3.3V logic level. Logic level refers to the specific voltage in which a signal can be generated and read by particular chips, for example a simple Uno operates at 3.3V. To overcome this issue a new form of communication was needed, this was swapped for UART communication methods, which sends data as a digital byte. The voltage was shifted using level shifters and the signal was additionally smoothed using capacitors and diodes. Placing the signal through this we were able to control the motors through the Raspberry Pi + servo hat, eliminating the need for another control system and freeing up space in the chassis. It also allows greater control and possibilities in the possibility. Our new control system can be seen in Figure 4. A render of the full Bender Mark 2 robot can be seen in Figure 5.

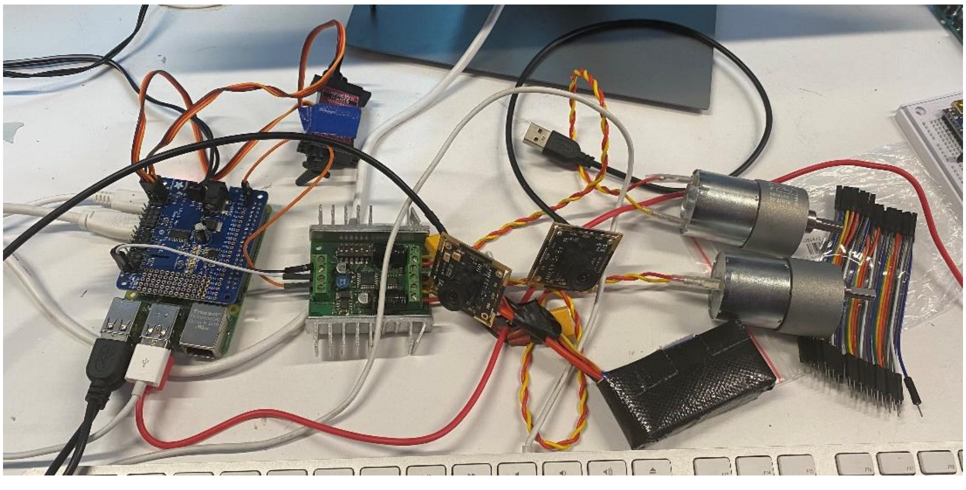

Figure 4 – New Control System for Bender Mark 2

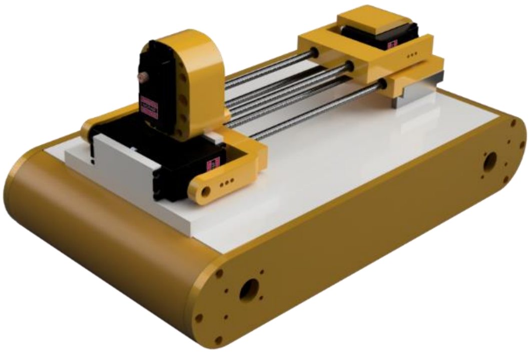

Figure 5 – Bender Mark 2 Render

Software

Vision

The S.A.R.T. robot has multiple capabilities regarding interpretation of its surroundings, including recognition of Hazmat warning signs and reading of QR codes (Figure 6, 7). All of our computer vision software runs on the control panel computer, using video feed received from the web socket server on the robot. This allows us to offload computations from the robot, preserving its computation power.

Our QR code reading program is a python script that uses the "pyzbar" package and its in-built QR code reading function. We apply rotation to the image at many angles and apply pyzbar to each rotation to increase efficiency. The output of this script can be seen in Figure 6.

Figure 6 – QR Code Reading

Our hazmat detection python script is a two-stage process running on the control panel. We first apply a YOLO v4 object detection model, trained on custom data, to calculate the location of the sign in the image. Once we have found the location of the sign, we apply a K-nearest-neighbours (with K=1) test (to the region of the image found by the YOLO v4 model) to classify the sign. We use sample sign images as our KNN point cloud. The final output of this process can be seen in Figure 7. The biggest advantage of this method is that the YOLO v4 model only calculates position, and does not do classification. Doing classification in the YOLO v4 model would require roughly 20x more training data to achieve the same accuracy.

We have also experimented with adding multithreading to the hazmat detection python scripts. We now run every comparison check (between sign samples and camera cutout) on separate threads, and we have seen approximately a 2x boost in speed of detections.

Figure 7 – Hazmat Detection

4. Operational Procedures

Setup

The setup process of the robot and control panel was designed to be as simple as possible. As mentioned previously, first responders in a rescue situation rate ease of use highly amongst the requirements of a rescue robot. Thus, one of our core design philosophies for user experience was simplicity, meaning the setup process is remarkably straightforward and intuitive.

Mission Strategy

During operation, the teleoperator has primary control of the robot using their choice of a keyboard or any compatible controller, with easy switching between robot driving and arm operation with a single button press. The teleoperator's primary vision for navigation will be the optical cameras however the suite of other sensors including map of the environment are displayed on the control panel so that the teleoperator has all the information necessary to control the robot.

Given that in a rescue situation, resetting or freeing the robot of an obstacle is not possible, this means that the teleoperator really only gets one attempt at the rescue situation so extreme caution has to be taken. For example, if in a situation, visibility of the track ahead is blocked by on obstacle, therefore meaning that it is unknown what is on the other side of the obstacle, it is in the best interest of the teleoperator and the entire rescue operation to perform a risk analysis. Given that the stakes are incredibly high as the operator has little opportunity to reset the robot in a real-world situation, unless the teleoperator is extremely confident that it is safe to proceed, backtracking in an attempt to find a less risky, safer route is to be taken. Although this backtracking will likely result in a slower response time, it is the best outcome overall, as if the teleoperator makes the decision to take the risk and venture without aid from the robot's cameras, the robot is of no use whatsoever if it is stuck and cannot proceed into the situation, collecting valuable intel that can prove extremely useful in rescue operations. Referring back to the risk analysis performed by the teleoperator, it is not always possible or viable to backtrack in an attempt to find a safer route, given situation-specific individualities. This is why it is not a concrete rule to backtrack in an attempt to find a safer way, as in some situations, the risk of venturing into a situation with minimal to no aid from the robot's cameras is less than the risk if the robot does not reach the destination in a certain amount of time. Because of this potential, the decision is left up to the telecommunicator who is operating the robot to make the decision in order to achieve the most favourable outcomes given the constraints and individualities of the situation.

Pack-up

If the operator has already recovered the robot, the power-off process has three steps. The robot can be safely shut down using the power options in the interface. The control panel can then be turned off in the usual way in desktop operating systems. Once the device has been safely powered off, power can be cut by depressing the control panel power button. Power can then be cut to the robot using the implemented power isolation switch. Additional pack up steps may include placing the robot in its foam-lined hard carry case. Given that the decision was made to switch from a drill battery to a LiPo battery in order to make better use of weight and space, this means that the battery cannot be allowed to run flat and therefore should never be left connected to the robot when packed away. A LiPo alarm is fitted inside the robot to alert the teleoperator and people in close proximity to the robot that the battery is running flat and needs to be charged soon. The sounding of the LiPo alarm does not mean that the run has to be stopped immediately but does mean that the battery needs to be charged closely following the end of the run.

Alternatively, the battery in the robot can be removed, although assuming it is not completely flat it is safe to leave it in indefinitely.

5. Experiments and Testing

The SART uses a range of test methods to improve the functionality of the robot. These test methods are of modular design to test a range of engineering methodologies and validate changes to the robot. The First stage of testing is utilising a flat box which is used to simulate driving ability on 'flat ground', this test method was primary used to test camera angles and locations. Second test method involved a range of vertically angled platforms which, allowed the S.A.R.T to test the rigidity of the chassis and validate its ground clearance.

The third test method was an adaptation of the second featuring more gradual steps to softly test the robot's functionality. Lastly, the fourth test method involve the S.A.R.T using a range of PVC pipes to simulate log and or smooth climbs. This method was far by the hardest and allowed us to test the robot in its entirety (with the arm). The use of these test methods has greatly improved the functionality of the robot through rigorous engineering physical testing

6. Future Developments

Future developments will continue to focus on vision processing and autonomy. This will include taking advantage of our new hardware's capabilities in machine learning and vision processing to improve our autonomous functionality and computer vision processing. In future we would like to put significant development into a new innovative control interface, utilising virtual and augmented reality technologies to provide a significantly improved interface between the teleoperator and the robot.

7. Conclusions

The S.A.R.T Bender Mark 2 represents an improved design of the Bender Mark 1 robot with the addition of a robotic arm and attached camera. The arm was added to the design to enable our robot to undergo dexterity and manipulation tests, which had not been achieved satisfactorily by any of the previous iterations of S.A.R.T robots. The addition of a robotic arm to this iteration not only allows us to compete in more tests and therefore gain more points in the competition, but also expands the diversity of applications of our robot in rescue situations.

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9. Appendix

Component	Price (USD)	Quantity	Total (USD)
Raspberry Pi 4	$ 45.00	1	$ 45.00
MLX90640 IR Camera	$ 66.72	1	$ 66.72
ELP 5MP HD USB Autofocus Camera	$ 56.23	3	$ 168.69
Adafruit SGP30 CO2 / TVOC Sensor	$ 19.95	1	$ 19.95
MLX90614 Infrared Temperature Sensor	$ 7.57	1	$ 7.57
50:1 Metal Gearmotor 37Dx54Lmm 12V	$ 35.00	4	$ 140.00
2-pole rotary switch	$ 6.16	1	$ 6.16
Cables	$ 17.11	1	$ 17.11
Track	$ 25.11	3	$ 75.33
Servo Tubing Connector	$ 6.95	1	$ 6.95
Carbon Fibre Tube (1m x 24mm)	$ 30.00	1	$ 30.00
Acrylic Sheet (4mmx400mmx400mm)	$ 10.00	1	$ 10.00
Gripper	$ 40.00	1	$ 40.00
Turnigy 1300 mAh 3S 25C Lipo Pack	$ 12.87	2	$ 25.74
Ultimaker ABS 3D Printer Filament 1kg spool	$ 32.00	1	$ 32.00
Quanum 12V-5A (7.2 - 25.2V) Dual Output UBEC	$ 10.25	1	$ 10.25
Sabertooth 2x12 Dual Motor Driver	$ 97.98	1	$ 97.98
Adafruit 16-Channel PWM Servo HAT Raspberry Pi	$ 23.96	1	$ 23.96
Total			**$823.41**

Component	Price (USD)	Quantity	Total (USD)
SE830 Waterproof Protective Case	$87.00	1	$87.00
UDOO x86 Ultra	$267.00	1	$267.00
Energizer AC Sine-Wave Inverter	$50.64	1	$50.64
AOC E1659FWUX USB Monitor	$92.38	1	$92.38
Ubiquity Unifi AP AC Pro Access Point	$148.84	1	$148.84
Power-Over-Ethernet Injector	$8.00	1	$8.00
Microsoft All-In-One Media Keyboard	$45.60	1	$45.60
Turnigy 4000mAh 4S LiPo Battery	$36.95	2	$73.90
Acrylic Sheet (3mm)	$20.00	1	$20.00
Power Button	$3.00	1	$3.00
Total			**$796.83**