RRL2023_BART LAB Rescue Robotics Team_Thailand

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Info

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Team Country:	Thailand
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Team Qualifying Video URL: https://drive.google.com/drive/folders/1xAnxN_6YWFQePT1BONabH_rsqn-H8M6y

***Abstract*—This paper is about the BART LAB team's participation in the 2023 RoboCup Rescue Robot competition. This team has been participating in regional and global events since 2006, focusing on the development of a reliable lightweight semi-autonomous rough-terrain robot. This paper provides an overview of the system, including manufactured parts, CAD files, prospective programs, and implemented control systems such as the locomotion system, communication hardware, manipulator pose estimation software (MPE), and user interface (UI). The BART LAB team is developing a reliable rescue robot to contribute to the RoboCup Rescue community and use it in real disaster situations around the world.**

***Index Terms*—RoboCup Rescue, Team Description Paper, independent flippers, disaster, manipulator.**

I. INTRODUCTION

BART LAB Rescue Robotics Team is one of the rescue robotics teams from Thailand and presently consists of fifteen members and two robots. The first is a rough terrain robot calls as TeleOp VIII, which is composed of two functions (Tele-Operative and Autonomous function) and an aerial robot call as AerialBot II is introduced with light-weight mapping and a vital sensing system in this year. We constantly researching and developing robots and has participated in regional robot competitions since 2006.

In the 2008, Thailand Rescue Robot Championship (TRR 2008), we were one of the 8-finalist teams from 80 plus participating teams and received the Best-In-Class award for its autonomous robot. In early 2009, we attended the RoboCup Japan Open 2009 in the Rescue League with ten Japanese teams, where the team received second place. Additionally, we were awarded the 'SICE Award" for data collection and management of the autonomous robot. TeleOp VIII and TeleOp VII were shown in Fig. 1 and Fig. 2, respectively.

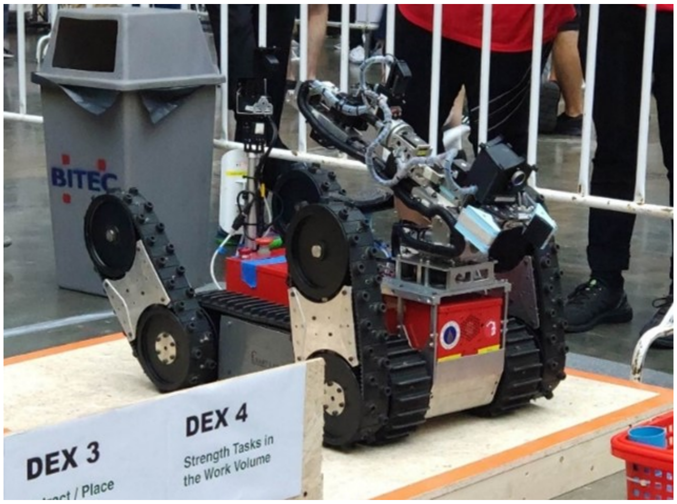

Fig. 1. TeleOp VIII is with BART LAB, Engineering faculty, Biomedical Engineering department, Mahidol University, Thailand

At the 2009 Thailand Rescue Robot Championship (TRR 2009), we were the Winner and awarded Best Autonomy for its autonomous robot. TRR 2009 was one of the most competitive Rescue Robot League in the work with more than 100 exceptional teams, consisting of six international teams from four countries (Australia, NuTech-R: Japan, NIIT-Blue: Japan, Jacobs University: Germany, Pasargard: Iran, and Resquake: Iran). In early 2010, the team attended RoboCup Japan Open 2010 was awarded 1st Place Rescue Robot Award. After commendable performance at these two competitions, we participated at World RoboCup Rescue 2010, Singapore as the official representative team. Finally, BART LAB Rescue Robotics team was awarded the 1st runner-up for its Rescue Robot.

In 2011 to 2015, our team continued to receive awards, 1st Place Rescue Robot Award and 1st Runner-up Rescue Robot Award at RoboCup Japan Open 2011 and 2012, respectively. Furthermore, the team was awarded the Best Autonomy Award at Thailand Robot Championship 2012 in the Rescue Robot League, 3rd Place Res-cue Robot Award at World RoboCup Rescue 2014, Brazil. In early 2015, the team attended RoboCup Iran Open 2015 was awarded the 3rd Place Rescue Robot Award.

Tele-operative robots are similar in their design yet have different performance, since TeleOp VIII has better driving components. Tele-operative robots are highly mobile robot with tracking locomotion systems, making the robots more mobile in testing arenas. The robots consist of four flippers, which are controlled independently to improve their mobility in various terrains (two flippers at the front end and two more at the rear end). The robots also employ manipulators which are controlled using inverse-kinematics. The victim-sensing unit is attached to the end-effector of this manipulator, to improve the victims sensing ability and retrieving information. The sensing unit contains various life signal detecting sensors, for example, thermal camera, real-time motion image detector carbon dioxide sensor, and two-way voice communication system. The manipulator has multiple degrees of freedom with both rotational and prismatic joints, giving the robot a compact folding-size with a highly efficient workspace. The manipulator is controlled by a special device (Phantom Omni haptic device) for fine movement of the end-effector. The autonomous robot of the team is designed for victim identification using image processing and heat imaging technology. On the other hand, the autonomous function, navigates the TeleOp VIII by employing a laser-scanner system and an efficient algorithm which allows the robot to autonomously navigate in testing arenas without hitting walls. Figure 2 shows the previous version of the autonomous robot which is used as a base for a developed autonomous algorithm in the TeleOp VIII.

The last one, the AerialBot II introduced this year. The robot bases on the commercial robot with the novel lightweight structure with a laser range finder and IMU for 3D maps with 3D map visibility Graph Technique. However, the teleoperative and autonomous robots are equipped with SLAM system to generate 2-D maps to guide the responders after the rescue robots raid the disaster area.

RoboCup Rescue is an opportunity towards a remarkably efficient robot exercise in response to a disaster. To handle such situation regardless of being actual or exercise, robot and the team behind it would get through high amount of data, decisions, control parameters, time shortage and stress. Reliable rescue robotics in terms of structure robustness and control would consider as the critical factors for a robot. For those reasons our team is mainly focusing on these aspects for a rough terrain robot. To obtain so, our introduced robots have had four independently controlled flippers, particular platform and control system. These require some principle as: components compactness to save space, the ability to withstand high impact or unforeseen situations and harmonic design to combine subcomponent together for having expected functionality and well interactive parts to connect hardware and software together well.

In conclusion, we comprise of highly mobile rescue robots in relation to those built by Thai teams for previous World RoboCup Rescue Leagues. Over the years, we have improved its autonomous robot and the quality of real-time map generation. The ultimate aim of our research and development team is to produce reliable rescue robots to be employed in real disaster situations around the world and to be improved a possibility of victims searching for a rescue team.

A. Improvements over Previous Contributions

In the most recent robot, each component was interdependent in terms of adjustment and installation. This means that any misalignment in one part can result in incorrect positioning in other parts. For instance, a platform that serves as a robust chassis can cause propulsion drive malfunctions if it experiences deflection. However, in the latest BART LAB robot, all parts are designed and engaged independently as modules. Various specialized connectors are used to connect the modules. The overall improvements are as follows:

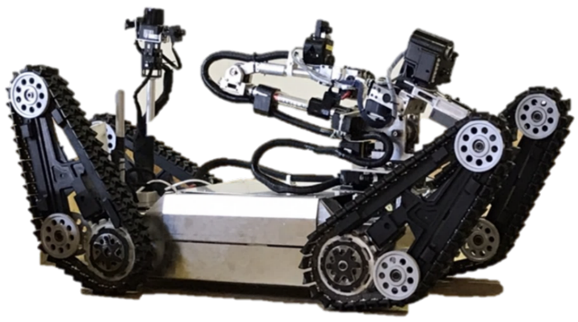
Fig. 2. TeleOp VII the previous iteration of the autonomous robot of BART LAB Rescue Robotics team

- Improved platform design based on data from previous models.
- New flippers' design form triangular shape to rectangular one
- Light Weight carbon-fiber-reinforced manipulator.
- Secondary communication plan in radio frequency (FR) band.

B. Scientific Publications

The team at BART LAB, specializing in biomedical and robotics technology, has spent 15 years building rescue robots. This robot has been successfully used in various conditions, such as robot competitions and real rescue missions [1], [2].To navigate unknown paths, an Observer-Based Controller (OBC) is used to calculate the changing acceleration and contact points [3]. The OBC compensates for these changes using a torque observer and predictable torque based on sensorless control [4], [5]. Recent research has shown that adding sensors to robots can improve their effectiveness in search and rescue missions [6] [7].

II. SYSTEM DESCRIPTION

TeleOp VIII is a new teleoperative robot designed and manufactured by the BART LAB team after TeleOp VII. This is a medium-sized Train Rescue Robot (TRR), which is the next-generation solution for disaster intervention in rough terrains. TeleOp VIII is a versatile robot equipped with various hardware packages and actuators, including a manipulator arm, four independent flippers that can be changed, replaceable end-effectors, a thermal camera, digital cameras, and a laser pointer. It is designed to meet the requirements of disaster response and military forces in terms of strength, search, and manipulation, and is capable of operating on rough terrain. The robot is lightweight, energy-efficient, and has a modular design that allows for the easy installation and maintenance of components. The flippers can be angled using a configurable control system and can be replaced with longer flippers if needed.

The robot is made of materials such as engineering plastics and reinforced carbon fiber, which provide strength, rust resistance, and low density. The structural and suspension components of the robot were designed and analyzed using finite element method (FEM) software to ensure their effectiveness [8]. The design of the robot was based on the anticipated tasks, and its overall CAD model was evaluated for weight and power. Mobility and maneuverability tests were performed to ensure that the robot could accomplish its intended task

A. *Hardware*

1) Locomotion: Our robots use tracked locomotion systems and are equipped with four independently controlled flippers to improve their mobility. Their movement is similar to that of a tank, where the left and right tracks move in the same direction and speed to move forward or backward, respectively. If the tracks moved at different speeds, the robot turned based on the velocity of each track. The maximum speed is approximately 0.5 m/sec, and the maximum angular velocity is 1.8 rad/sec. To remain stable while moving up or down ramps or stairs, the robot must move at an appropriate speed. Figure 10 shows a comparison between the CAD design of the robot and a real image.

2) Manipulation: This section focuses on an eight-degrees-of-freedom manipulator that is present in tele-operative robots. The manipulator was designed to withstand high vibrations and strong shocks while moving on rough terrain. Despite its light weight, it has a strong structure. The robot had a compact folding size, but its workspace was optimized using both rotation and prismatic joints. The victim sensing unit is attached to the end of the manipulator, which helps in searching for and identifying the condition of the victim. Fig. 11 illustrates the degrees of freedom of the manipulator.

3) Power (Batteries): The majority of time TeleOp VIII will use 4 of 24V Li-Po batteries, with 6000 mAh, as the main power source for both the platform and manipulator. For some experiments, a new generation battery such as OXIS will probably be tested.

4) Sensors and cameras: Each corner of the robot was powered by two DC brushless motors, and each motor had a Hall Effect sensor that served as an encoder. Each flipper also has its own Hall Effect sensor to locate the home position physically. The platform features four cameras, MCM-4350FISH, placed at the front and back of the robot. To measure the inertial and platform angles of the robot, we used an MPU 6000 6-axis IMU. The robots were equipped with a victim sensing unit that included a carbon dioxide sensor (C), heat sensor (D), Sensor Range Finder (E), and thermal sensor, which were used to detect vital signs. Fig. 3 shows the sensors used in the proposed system.

The detection system for the autonomous function is classified into two types:1) image detection from the camera, which is used to monitor and analyze victim data, including motion detection, QR code detection, and text reading in an image. 2) Thermal sensors that detect the victim's heat within an area. The manipulator is equipped with thermal sensors to search and locate any heat source that could indicate the presence of the victim. QR code detection is achieved through image processing, which can be performed by capturing a video or a photo. A QR code detection flowchart is shown in Figure 4.

Fig. 3. Electrical components of our Robots: (A) Cameras (B) Carbon dioxide sensor (C) Heat sensor (D) Sensor Range Finder (E) Thermal sensor

Fig. 4. QR code detection process

Hazmat detection is implemented based on SIFT and Surf to detect key points in a photo. The Hazmat template contains a detection database. In real-time searching, the extracted key points are continuously compared with the database.

B. *Communication*

The BART LAB Rescue Robotics team employs access points connected via Wireless LAN 802.11AC 5 GHz to communicate through the robot and station using the bridging technique. The default setting is Channel 36, which is modifiable to any other available requested channel.

C. *Software and Human-Robot Interface*

The control method and human-robot interface were categorized into two groups, as shown in Table IV in the Appendix. The first group pertains to the control and interface of the tele-operative function, while the second group pertains to the control and interface of the autonomous function. Further details on these two groups are provided below.

1) Control Method and Human-Robot Interface of Tele- Operative Function: The method of controlling the tele-operative robots and human-robot interface is shown in Figure 5. The control system on the robot communicates with the operator station using Wireless LAN 802.11AC access points. The robot has an onboard access point that receives commands and sends processed data to the station, which comes from USB devices and sensors such as cameras, microphones, speakers, Hokuyo laser range finders, or scanning range finders. The onboard computer communicates with the robot through the USB and serial ports, and it controls the propulsion, manipulator, other actuators, and hardware using a PID control system. The robot also has an emergency button system that can stop

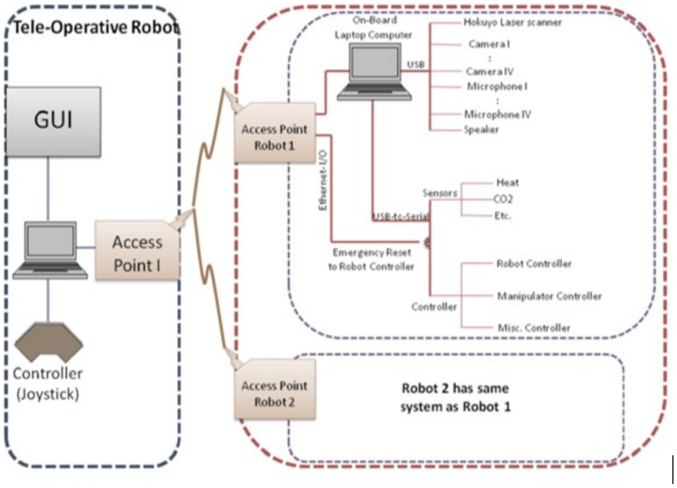

Fig. 5. This diagram illustrates the control scheme for TeleOp VII

or recover its control system. The operator station is a mobile unit of the size of a suitcase, which includes a laptop, robot controllers, backup power, power connection, wireless access point, and a monitor. Each component of the operator station is described in detail in the following sections (Fig. 6)

- Wireless Access Point: The Wireless Access Point is connected to the on board laptop.
- Monitor System: We modified the lid of the suitcase to attach a touchscreen monitor (300 250 50 mm or 12 inch). The monitor displays the real-time camera output on the robot, GUI, sensor data display (e.g., heat, CO2, etc.), robot heading, communication controller, configuration display of robot platform, pre-set robot configuration controller, and controller for inverse-kinematic manipulator.
- Backup Power: We used the UPS for backup and to protect the operator station. We need to use electricity for just a few minutes to set up the operator station system before the competition. The UPS has a capacity of 1000VA/550 watts and can provide backup power for approximately 20-30 minutes.
- Laptop: The laptop is the main processor in the operator station as a server. It should have at least one LAN channel, 1 USB channel, 1 speaker channel and 1 VGA port.
- Suitcase: Pelican 1520 was used. It is watertight, crush-proof, dust proof, and very strong. Pelican 1520 has an interior storage area of 18.0612.896.72 inch.
- Robot Controllers: We Gamepad-type controllers are used. It is a type of controller held in two hands, where the fingers, particularly the thumbs, are used to provide the input signal. It is used to control the robot flipper and manipulator. Fig. 7 displays this information on the GUI. (A) Four views from four onboard cameras and sensor data (for example, Heat, CO2), robot posture, communication controller, preset controller configuration, and manipulator inverse kinematic controller.

2) Control Method and Human-Robot-Interface of the Autonomous Function: The control scheme utilized for the autonomous function was similar to that of the teleoperative function. The difference between these control systems is that the robot navigates autonomously and can also detect a victim automatically. Additional aspects of autonomous navigation, such as map generation, navigation, and localization, are discussed later. At the starting point, the autonomous robot must be launched manually, after which it must travel autonomously.

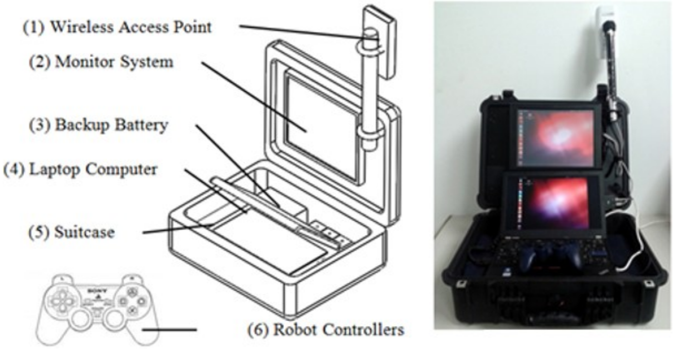

Fig. 6. BART LAB Rescue Robotics operator station: (A) CAD design (B) Our Operator's Station

Fig. 7. Image shows the framework of (A) GUI of the tele-operative (B) GUI of the autonomous function

3) Map generation/ printing: The operation of the robot was primarily controlled by the ROS. The G-Mapping package from the open SLAM was used to generate a high-resolution occupancy grid map with a resolution of 0.05 meters per pixel. The map is created using two inputs: first, the laser range finder, which measures the distance of objects or structures around the robot within a 180-degree field of view; and second, the odometry of the robot, which is calculated by the wheel encoder to determine the distance the robot travels in the axial direction. The orientation of the robot was also measured using an inertia measurement unit (IMU). An example of a map generated in the RoboCup Iran Open 2015 competition is shown in Fig. 8.

4) Fuzzy Logic Algorithm for Autonomous Running with Obstacle Avoidance: To enable obstacle avoidance in the autonomous mode, our robot uses the fuzzy logic algorithm. The laser range finder collects distance information from ten directions following the pan scan direction, which is then filtered to reduce errors. The membership function for the fuzzy sets is created from the filtered data, which ranges from zero to one as the algorithm input. The fuzzy rule design is based on obstacle avoidance and distance reduction as the robot moves around the area, with the robot slowing down as it approaches the obstacles on each side of the driving system. The fuzzy set was divided into three categories: low, medium, and far, corresponding to obstacles, and the minimum distance

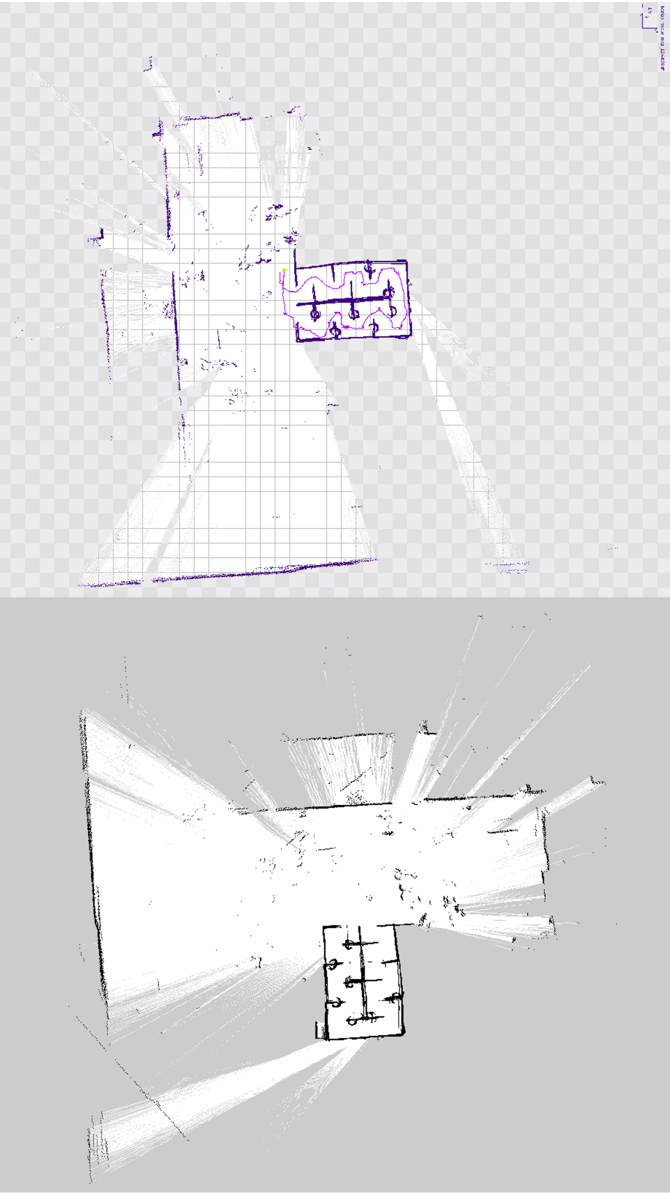

Fig. 8. The generated map in RoboCup 2022 Bangkok, Thailand

was chosen for obstacle avoidance. The if-then Rules are used to determine the fuzzy outputs based on the orientation of the robot and the velocity of each driving motor. The output is computed in real-time based on the environment and sent to the propulsion unit to respond immediately to the environment.

III. APPLICATION

A. Set-up and Break-Down

The operator station for controlling and communicating with the AIRobot is similar to the previous model, and has a compact suitcase size. It is designed to be user-friendly, and starting a task is as simple as turning on a laptop or robot. The operator could easily access the robot via Wi-Fi.

B. Mission Strategy

The robot had a configuration mode that allowed the operator to specify the task at hand. This mode enables the robot to configure its mechanical, sensory, and control systems to reduce the driver's workload. Additionally, the robot has relatively lower inertia owing to its lower weight and high strength, which increases its mobility and maneuverability. The new carbon fiber manipulator is expected to be more agile and accurate when using the same approach.

C. Experiments

The experiments conducted for robots can be divided into two categories: component experiments and robot experiments. To ensure the functionality of the flipper, FEM analysis was performed on its model, and it was subjected to different forces and bending moments. The flipper parts were also tested under specific weights by flexural testing to confirm the FEM data. Additionally, the BART LAB at Mahidol University in Salaya, Thailand, has a constructed arena where various rescue robots tests such as maneuvering, mobility, and dexterity can be performed and practiced.

D. Application in the Field

In August 2014, a six-story building under construction in Pathumthani, Thailand collapsed, injuring several people trapped inside. The BART LAB Rescue Robotics team was called in to assist with the rescue mission, and arrived at 1:00am on August 12th to collaborate with the Director-General of the Department of Disaster Prevention and Mitigation. The collapsed building had a sandwich structure, and some injured people were trapped at depths that were difficult to access. While the BART LAB Rescue Robot was designed to operate in rough and complex terrain, its height of 60 cm limited the regions that it could access. The rescue team made holes to access to 3-4 floors to locate survivors, and the BART LAB Rescue Robot was assigned to survey the scene and provide more information on the location of the survivors and the structure of the collapse (Fig. 9). During the rescue operation at the U-place condo collapse site, the BART LAB Rescue Robot was remotely operated from an outside station to survey the scene and provide information on the location of the survivors and the structure of the collapse. However, the movement of the robot was limited owing to the narrow and small spaces and obstacles such as steel rods that reinforce the concrete structure. This experience provided valuable feedback for future improvements and developments of rescue robots, with the ultimate goal of producing a reliable rescue robot for application in real disaster sites worldwide. Since 2006, BARTLAB has developed several rescue robots, and the on-site experience at the U-place condo collapse has motivated the team to improve both mechanical and communication systems. The latest version, TeleOp VIII, is expected to show better performance in mobility, dexterity, and communication than the previous version. However, the installed manipulator is only capable of manipulating with a force lower than 1 kg, and the team plans to enhance its capability in the next version while reducing the robot's weight, size, and cost.

Another important project about the "Informational system for management of flood and landslide disaster areas using a distributed heterogeneous robotic team" was initialized within

Fig. 9. On-site experience at U-place condo, Pathumthani, THAILAND

the international e-ASIA Joint Research Program and gathered research teams from Japan, Russia, and Thailand, each contributing unique experience and expertise toward achieving common research goals. Based on our experience in different disaster response research, theoretical and practical, we developed a concept of a joint international operation framework for disaster site management using distributed heterogeneous UAV/UGV/USV robotic teams. The results of the successful 3-year project, including approaches, models, and algorithms, refer to corresponding research papers for further details [7]–[10].

IV. CONCLUSION

In conclusion, despite not having a finished robot at this point, our team has made significant progress over the years in terms of motivation, experience, and knowledge. Although we cannot currently demonstrate the extent of our improvements in comparison to the previous robot, we are confident that further learning and enhancements are inevitable during this journey.

APPENDIX A
TEAM MEMBERS AND THEIR CONTRIBUTIONS

Jackrit Suthakorn	Executive Advisor
Songpol Ongwattanakul	Co-Advisor
Shen Treratanakulchai	Co-Advisor
Nantida Nillahoot	Senior Member and HRI
Pittawat Thiuthipsakul	Senior Member
Branesh Madhavan Pillai	Control Supervisor
Sakol Nakdhamabhorn	Control Supervisor
Witthawin Sae-Lee	Team Leader
Tanapat Thongprong	HRI
Dileep Sivaraman	Mechanical Designer
Panuwat Oiamwong	Mechanical Designer
Tanadul Somboonwong	Programmer
Daral Maesincee	System Integrator
Thitamorn Panyawongngam	Mechanical Designer

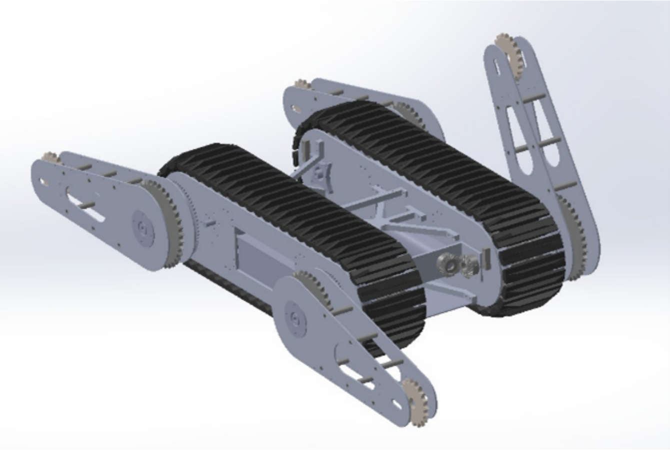

Fig. 10. CAD of TeleOp VIII platform

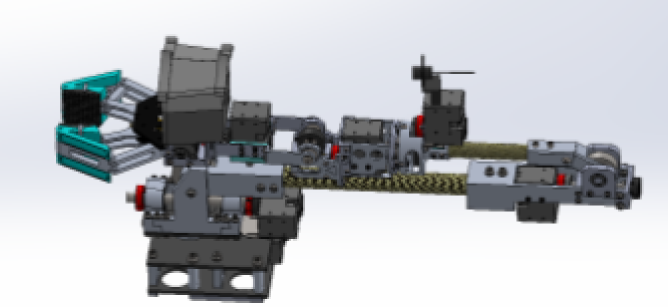

Fig. 11. CAD representation of the Eight degrees-of-freedom manipulator

APPENDIX B
CAD DRAWINGS

APPENDIX C
LISTS

A. Systems List

For the operator station list, please refer to Table II

TABLE I
MANIPULATION SYSTEM

Attribute	Value
Name	TeleOp VIII
Locomotion	Chain-rubber tracked
System Weight	55kg
Weight including transportation case	75kg
Transportation size	0.6 x 0.6 x 0.5 m
Typical operation size	803 x 532 x 587 mm
Unpack and assembly time	120 min
Startup time (off to full operation)	15 min
Power consumption (idle/ typical/ max)	60 / 200 / 800 W
Battery endurance (idle/ normal/ heavy load)	2240 / 120 / 60 min
Maximum speed (flat/ outdoor/ rubble pile)	4 / 1 / - m/s
Payload (typical, maximum)	1/ 2 kg
Arm: maximum operation height	100 cm
Arm: payload at full extend	1kg
Support: set of bat. chargers total weight	4kg
Support: Charge time batteries (80%/ 100%)	90 / 120 min
Support: Additional set of batteries weight	2kg
Cost	25000 USD

TABLE II
OPERATOR STATION

Attribute	Value
Name	TeleOp VIII
System Weight	6kg
Weight including transportation case	12kg
Transportation size	45.5 x 32.7 x 17 cm
Typical operation size	45.5 x 32.7 x 62 m
Unpack and assembly time	1 min
Startup time (off to full operation)	1 min
Power consumption (idle/ typical/ max)	60 / 80 / 90 W
Battery endurance (idle/ normal/ heavy load)	10 / 5 / 4 h
Cost	1600 USD

TABLE III
HARDWARE COMPONENTS LIST

Part	Brand & Model	Price($)	Num.
Drive motors	Maxon EC 40 170W	1126.7	4
Gearhead	Maxon GP 42 C		4
Motor drivers	EPOS4 compact 50/8		4
Flipper Motor	Maxon EC 40 170W	1528.2	4
Gearhead	Maxon GP 42 C		4
Motor drivers	POS4 compact 50/8		4
Gripper Motor	DYNAMIXEL XL430-W250-T	2454	2
Manipulator Motor	Dynamixel XM540-W270-R		5
Reducers	Matex LGU75M		2
Raspberry Pi	Raspberry Pi 3B+		1
Computing Unit	Axiomtek with Intel Core i7-6600	1392	1
WiFi Adapter	Metal 5shpn mikrotik	100	1
IMU	MTi-7-DK	500	1
Cameras	HDQ13 140 HD 1080P WIFI	60	5
Depth Camera	Realsense d435i	200	1
Infrared Camera	FLIR Lepton Dev Kit V2	240	1
CO_2 Sensor	ExplorIR CO2 sensor	120	1
Battery Chargers			4
Rugged Operator Laptop			1

B. Hardware Components List

For the hardware components, please refer to Table III.

C. Software List

For the software list, please refer to Table IV

ACKNOWLEDGMENT

BART LAB team would like to express its special thanks of gratitude to Mahidol University and our major sponsors, e.g., TCELS – Ministry of Science and Technology of Thailand, PTT, PEA and ERAWAN rubber. We also would like to thank NIST, RoboCup Federation, and RRL members for their contribution to the Rescue Robot Research. Lastly, we would like to thank every family of all BART LAB members who understand, support, help and guide us a lot in finalizing this project within the limited time.

TABLE IV
SOFTWARE LIST

Name	Version	License	Usage
Ubuntu	20.04	open	
ROS	Melodic	BSD	Hazmat Detection
OpenCV [11], [12]	3	BSD	2D SLAM 3D
Hector SLAM [13]	0.4.0	BSD	Mapping
EPOS Studio		BSD	Operator Station

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