RoboCup Rescue 2016 Team Description Paper
BART LAB Rescue Robotics Team (Thailand)

Jackrit Suthakorn*, Songpol Ongwattanakul, Choladawan Moonjaita,
Peerapat Owatchaiyapong, Pittawat Thiuthipsakul, Korn Borvorntanajanya,
Suwipat Chalongwongse, Branesh Madhavan Pillai, Maria Chatrasingh, and Nantida Nillahoot

Info

Team Name:	BART LAB Rescue Robotics Team
Team Institution:	Center for Biomedical and Robotics Technology (BART LAB) Faculty of Engineering, Mahidol University 25/25 Putthamonthon 4 Road, Salaya, Nakorn Pathom 73170 THAILAND
Team Leader:	Choladawan Moonjaita
Team URL:	www.bartlab.org

Abstract—**BART LAB Rescue Robotics Team is from Thailand, has been participating in RoboCup both Regional and World RoboCup since 2006. BART LAB has won several awards from RoboCup, e.g., 2nd Prize from World RoboCup 2009, 3rd Prize from World RoboCup 2014, 1st Prize from RoboCup Japan Open in 2010 and 2011, 1st Prize from Thailand Rescue Robot Championship (Thai Open) in 2009. The team has also received acclaim during its participation in various international events. The team consists of two robots; one tele-operative robots and one autonomous robot with high mobility and completed navigation and vital sign sensing system. Their highly mobile attribute is a result of the four independently controlled flippers of the robots. The tele-operative robot is controlled using a controller while the autonomous robot navigates itself through the arena using a laser-scanner. The robots have similar physical structures and systems. The system used for mapping is SLAM whereas the one used for locomotion is the fuzzy logic algorithm. On the other hand, the physical structures consist of a platform and manipulator, where the manipulator contains the sensors required for victim detection. The main goal of our research and development team is to produce reliable rescue robots to employ in a real disaster situation around the world.**

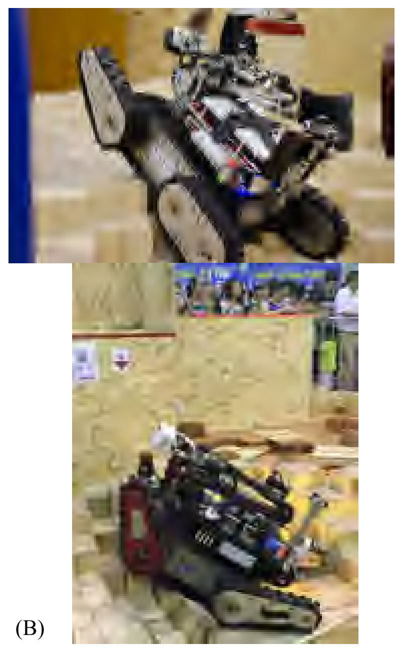
***Index Terms*—RoboCup Rescue, Rescue Robot, Disaster**

I. INTRODUCTION

BART LAB Rescue Robotics Team is a one of rescue robotics team from Thailand and presently consists of more than ten members and two robots. The two robots are composed of one Tele-Operative robot (TeleOp V) and one autonomous robot (AutoBot IV). We constantly researching and developing robots and has participated in regional robot competitions since 2006.

In 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.

(A)



(B)

Fig. 1. TeleOp IV - our previous version (A) and TeleOpV (B) are the two tele-operative robots in BART LAB Rescue Robotics Team. Both robots employ track locomotion with four independent flippers, and are equipped with manipulator which is controlled using inverse-kinematic algorithm for their capabilities in search and retrieve victim information, similarly to robots in [1, 2].

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. There, the team was awarded the 1st runner-up for its Rescue Robot.

In 2011 to 2015, the 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 Rescue Robot Award at World RoboCup Rescue 2014, Brazil. In early 2015, the team attended RoboCup Iran Open 2015 was awarded 3rd Place Rescue Robot Award.

Tele-operative robots similar in their design yet have different performance, since TeleOp V has better driving components. Tele-operative robots are highly mobile robots with tracking locomotion systems, making the robots more mobile in orange and red 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 ability to sense victims and retrieve information. The victim-sensing unit contains various life-signal detecting sensors, for example, heat sensors, 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 autonomous robot of the team is designed for victim identification using image processing and heat imaging technology. AutoBot IV, the autonomous robot, navigates by employing a laser-scanner system and an efficient algorithm which allows the robot to navigate in the yellow arena without hitting walls. The tele-operative 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.

In conclusion, we comprises 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.

Fig. 2. Autonomous robot of BART LAB Rescue Robotics team, AutoBot IV. This robot has a track-based locomotion system with sensors for the victim identification system, which uses image processing and heat imaging technology.

II. SYSTEM DESCRIPTION

A. *Hardware*

- **Robot Locomotion**

Our robots utilize tracked locomotion systems. Moreover, the tele-operative robots are equipped with four independently controlled flippers to enhance their mobility. The locomotion of these robots is similar to a tank-like system. When the left and right tracks are moving in the same direction, at the same speed, the robot moves either forward or backward. Once the left and right tracks start moving at different speeds the robot will make a turn with respect to the velocity of each track. The maximum speed of the tele-operative robot is almost 0.5 m/sec. On the other hand the robot has a maximum angular velocity of 1.8 rad/sec. To maintain stability during movement up/down a ramp or stairway, the robot has to move at an appropriate speed. Figures 3 (A) and 3 (B) compare the CAD and real image of the robot.

- **Manipulation/ directed perception**

In this section, we discuss the six degrees-of-freedom manipulator that can be found on the tele-operative robots. The manipulator is designed to perform in a high vibration environment with strong shock absorption during movement along a rough-terrain. The manipulator is relatively light-weight and strong based on its structure. The folding size of this robot is very compact while the workspace is optimized by using both rotation and prismatic joints. The victim sensing unit is attached to the end-effector of the manipulator, which improves the ability to search and identify the victim’s conditions. Figure 4 shows the manipulator’s degrees of freedom.

(A)

(B)

Fig. 3. (A) CAD of TeleOp V platform (B) TeleOp V in step field

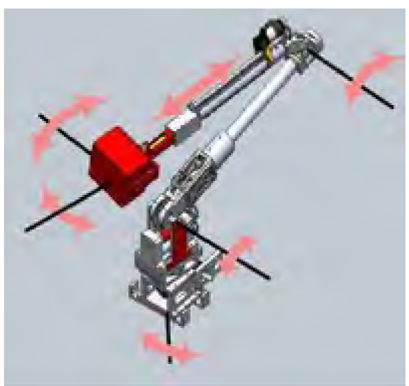


Fig. 4. CAD representation of the six degrees-of-freedom manipulator

- **Sensors**

The robots are equipped with a victim sensing unit which contains various necessary sensors to detect victim life-signals. The sensors utilized in our system are listed as shown in Figure 5.

The autonomous robot detecting system is divided into 2 types: 1) image detection from camera is used to monitor and analyze the data from victim such as motion detection, QR code detection, and reading the text in an image and 2) heat sensor detection to determine the heat of the victim inside the arena. Thermal sensors are mounted on a servo motor to allow for the sweep to search the heat of a victim.

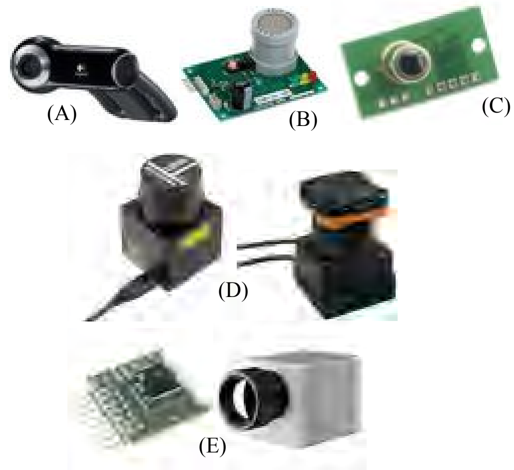


Fig. 5. Electrical components of our Robots: (A) Cameras (B) Carbon dioxide sensor (C) Heat sensor (D) Sensor Range Finder [5] (E) Thermal sensor [6,7]

The autonomous robot is divided into two main physical structures, the platform and the manipulator. The platform of the robot has the driving system whereas the second part consists of the manipulator and sensors. The sensors that are attached to the manipulator include: camera, heat sensor, carbon dioxide sensor, and the laser range finder. Special properties of the manipulator are: rotation and extension. The manipulator works with the sensors shown in Figure 6.

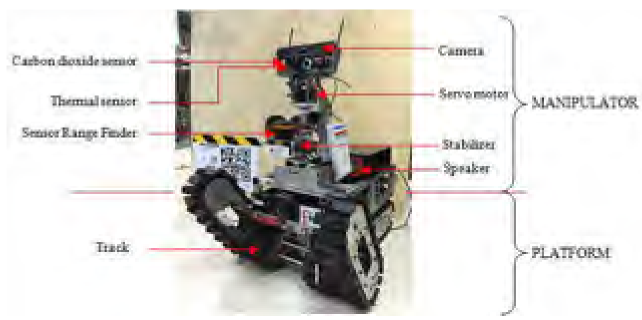


Fig. 6. Components of autonomous robot

QR code detection is a task, achieved by the autonomous robot by moving during the mission, therefore the input data is video type and detection is achieved through image processing. The QR code detection flow chart is shown below (in Figure 7).

Image processing allows for the detection of QR code throughout the different zones of the arena and is divided into multiple steps. The first step is, to import the video and sampling data into the image processing program. Second, the image goes through pre-image processing such as noise reduction and exposure calibration. The third step is, searching for QR code, therefore the program searches for three main points in the QR code for the purpose of alignment. The final step, the QR code is interpreted into data information that matches the QR code.

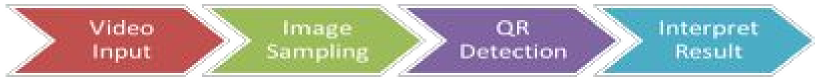


Fig.7. Diagram shows the process for QR code detection

B. Software and Human Robot Interface

- **Control Method and Human-Robot Interface**

Our control method and human-robot interface can be split into two groups: 1) Control and interface on tele-operative robot and 2) Control and interface on autonomous robot. These two groups are discussed in further detail below.

Control Method and Human-Robot Interface of Tele-Operative Robot

The control system for the tele-operative robots is illustrated in the Figure 8 below. The onboard controlling system communicates with the operator station via Wireless LAN 802.11A access points. The onboard access on the robot is connected to an onboard laptop. Various USB devices and sensors, for example, cameras, microphones, speakers, and Hokuyo laser range finder or Hokuyo scanning range finder, are connected to the laptop. The laptop communicates with the Robot-CPU using a USB port through a USB-to-serial port. The Robot-CPU controls the platform, manipulator and other subsystems. Under the platform and manipulator subsystems are each of the joint and drive (motor) controller module which employs our speed/position PID control system. Feedback control theory is therefore used extensively in our robots. The robot also has an emergency resetting system which prepares and recovers the robot's control system when it is operating in a remote area, far from the operator station. TeleOp V has identical control systems therefore allowing more flexibility to add robots to the team in the future.

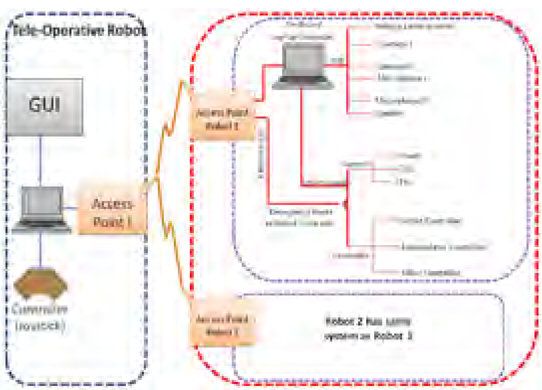


Fig. 8. This diagram illustrates the control scheme for TeleOp V

Operator station is a suitcase-sized mobile unit. The operator system contains a laptop computer, robot controllers, backup power, power-connection system, wireless access point system and monitor system. The system is placed in a waterproof and tough suitcase, which allows for easy transport and setup. The system is utilized to control and communicate with the Rescue robots. The laptop in the operator station is connected to the laptop on the robot. Due to the simple and convenient design of the BART LAB Rescues Robotics operator station shown in Figure 9 (A). The setup is almost immediate and ready to use that shown in Figure 9 (B).

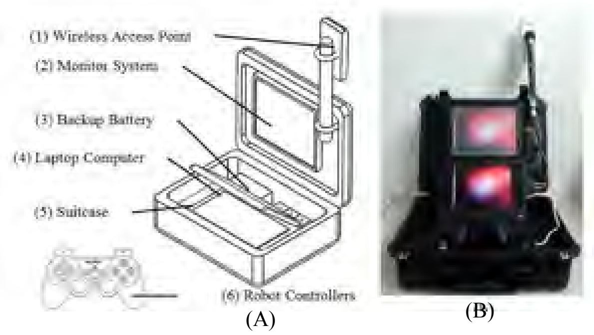


Fig. 9. BART LAB Rescue Robotics operator station: (A) CAD design (B) Our Operator's Station

(1) *Wireless Access Point*: Rescue Robot connected via Wireless LAN Ubiquiti NanoStation Loco M5 (Dimensions 163 x 31 x 80 mm, Weight 0.18 kg), frequency 5 GHz, Gain 13 dBi and 24 Volt adapter to communicate the robot. The wireless access point is mount on a pole has diameter of 25 mm and the length is 320 mm. The pole attaches the lid of suitcase via U- shaped screw. The Wireless Access Point is connected to an onboard laptop.

(2) *Monitor System*: We modified lid of suitcase to attach the touch screen monitor (dimensions 300 x 250 x 50 mm or 12 inch). Monitor will display all the video cameras which attach on the robot and also display information on the GUI, sensor data display (heat, CO_2, etc.), robot heading, communication controller, configuration display of robot platform, pre-set robot configuration controller, and a controller for inverse-kinematic manipulator.

(3) *Backup Power*: We used UPS for backup and to protect the operator station. We need to use electricity just a few minutes to setup the operator station system before competition. The UPS has a capacity of 1000VA/550 watts and it can backup power for about 20-30 minutes.

(4) *Laptop Computer*: Laptop Computer is the main processor in the operator station. It should have at

least 1 LAN channel, 1 USB channel, 1 speaker channel and 1 VGA port.

(5) *Suitcase*: We used Pelican 1520. It is watertight, crushproof and dust proof and very strong. The Pelican 1520 offers an interior storage area of 18.06 x 12.89 x 6.72 inch.

(6) *Robot Controllers*: We used gamepad type controllers. It is a type of controller held in two hands, where the fingers, especially the thumbs are used to provide input signal. It is used to control the robot flipper and robot manipulator.

(7) Information displayed on the GUI of the tele-operation robot as shown in Figure 10 (A) includes 4 viewing areas from 4 onboard cameras, sensor data display (heat, CO_2, etc.), robot heading, communication controller, configuration display of robot platform, pre-set robot configuration controller, and a controller for inverse-kinematic manipulator

(A)

(B)

Fig 10. Image shows the framework of (A) GUI of the tele-operation robot (B) GUI of the autonomous robot

Control Method and Human-Robot-Interface of Autonomous Robot

The control scheme utilized for the autonomous robot is similar to that of the tele-operative robot. The difference in this control system is that the robot navigates itself autonomously and can also detect a victim automatically. Aspects of the autonomous robot's navigation, for example, map generation, navigation and robot localization, are discussed in further detail in next topic along with that the mechanism used to automatically identify victims is discussed in next topic. At the starting point, the autonomous robot has to be launched manually after which it travels autonomously. This autonomous robot will continuously report to the laptop at the operator station which is dedicated to the autonomous robot (GUI of the autonomous robot as shown in Figure 10 (B)).

- **Map generation/ printing**

Our robot is mainly governed by ROS operation. The software package used to generate a map is G-Mapping package from the open SLAM community. Firstly, the map is defined by an occupancy grid, which has a high resolution, of about 0.05 meter per pixel. There are two inputs that create the map, which are: 1) the laser range finder which is used to measure the distance of objects or structures around the robot at 180 degrees and 2) the odometry of the robot which is used by the wheel encoder to calculate the distance the robot has traveled in the axial direction. The robot's orientation is measured using the inertia measurement unit (IMU). Figure 11 shown our example map in RoboCup Iran Open 2015 competition.

Fig. 11. Our map generated in RoboCup Iran Open 2015

The Figure above shows the map generated at a previous competition using G-Mapping algorithm. Maps have a resolution of about 0.05 meters per pixel and the red mask shows the location of victims using heat detection whereas the blue mask shows the victim using QR code detection.

- **Fuzzy Logic Algorithm for Autonomous Running with Obstacle Avoidance**

Our autonomous robot uses the fuzzy logic algorithm to run and avoid obstacles. The fuzzy logic algorithm uses input range information collected by a laser range finder. The laser range scanner provides data from ten directions following the pan scan direction. Ten directions are chosen with the aim to reduce the amount of data and computation period within the algorithm. A filter is applied to reduce the error before the data is turned into the membership function for Fuzzy sets. The membership function is a range from zero to one and is used as the fuzzy input in the algorithm. This function is defined by the range of the distance collected by the laser range finder device. For the fuzzy rule design, obstacle avoidance and distance decrease as the robot moves around the area, therefore the robot reduces its speed at each side of the driving system. The fuzzy set is divided into three categories: low, medium and far. These fuzzy categories correspond to obstacles and choose the minimum distance for obstacle avoidance. The fuzzy outputs using the If-Then Rule 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 driving unit of the robot, to respond with the environment immediately.

C. Communication

BART LAB Rescue Robotics team employs five access points connected via Wireless LAN 802.11A to communicate among the two robots. Each robots are designated an access point to communicate with the two access points at the operator station with bridging technique. The Figure 12 below demonstrates the communication system of our robot. The default setting in our communication system is Channel 36 which can be modified to any other requested channel in the available range. We don't utilize any RF or Analog wireless communication.

Fig.12. Diagram of the operator station

TABLE I
FREQUENCY, CHANNEL/BAND, AND POWER TABLE WHICH DESCRIBES THE COMMUNICATION SYSTEM OF BART LAB RESCUE ROBOTICS TEAM.

Rescue Robot League		
BART LAB Rescue Robotics (Thailand)		
Frequency	**Channel/Band**	**Power (mW)**
5.0 GHz - 802.11a	36	To be determined

III. APPLICATION

A. Set-Up and Break-Down

Our operator station is a suitcase-sized mobile unit. The operator system contains two laptop computers, robot controllers (joysticks), backup batter, power connection system, wireless access point system and a large monitor system. The system is placed in waterproof, wheeled, and tough suitcase, which allows for easy transport and setup. The system is utilized to control and communicate with the two robots (TeleOp V, and AutoBot IV). One laptop is dedicated to the two tele-operative robots whereas one laptop is connected to the autonomous robot. The diagram below demonstrates the system for the operator station. Due to the simple and convenient design of our operator station, setup is almost immediate and ready to use.

B. Mission Strategy

BART LAB Rescue has two robots, one autonomous and one tele-operative robot. The tele-operative robot has a very high mobility, while the autonomous robot has its navigation system with automatic victim identification system, based on fusion sensing system. Therefore, the mission strategy is based on utilizing both robots to work simultaneously in the arena. The operators are switching to operate both robots during the mission.

C. Experiments

A year-round setup of the rescue robot arena is constructed for practice and training at Mahidol University, Salaya, Thailand. The arena consists of all the zones of the rescue arena; red, orange, yellow and blue zones. Therefore, BART LAB Rescue practices and conducts experiments frequently. The QR code task is also a part of the arena, as shown in Figure 13.

Fig. 13. QR Code task in the practice arena.

D. Application in the Field

On August 11, 2014, U-place condo tale, the six-storey building under construction, collapsed in Pathumthani, THAILAND. There were a number of injured people trapped in the collapsed building. BART LAB Rescue Robotics team was called by the rescue team to join the survey and rescue mission on site. At 01.00 am on August 12, BART LAB Rescue Robotics team arrived and collaborated with Director-General of Department of Disaster Prevention and Mitigation who was in charge of the rescue operation. The top floor of the building was under construction and collapsed into the sandwich structure. Some of the injured were trapped at different depths that were difficult to access from the outside. BART LAB Rescue Robot is designed to operate in rough and complex terrain. However, the height of the robot is 60 cm, which limits the regions the robot is able to gain access to. During the operation the rescue team made the hole to access 3 to 4 floors to locate survivors. The pre-observation was possible to indicate a survivor. BART LAB Rescue Robot was assigned to survey the scene and provide more information on the location of survivors and the structure of the collapse. The robot was remotely operated from the outside station and passed through the 6th floor to the 4th floor. The hole became narrower and lower, additional obstacles included the steel rods that reinforce the concrete structure. Due to these major obstacles, the movement of robot was limited. However, this is the first mission that BART LAB Rescue Robotics team experienced as part of an on-site operation (Figure 14). The collaboration with the rescue team provided the team with valuable feedback for future improvement and development.

Fig. 14. On-site experienced at U place condo, Pathumthani, THAILAND. Our ultimate goal is to produce a reliable rescue robot, through research and development, for application in a real disaster site around the world. We strongly believe that our team robots are prepared to perform a rescue task in the real world.

IV. CONCLUSION

Our main purpose to participate the RRL is to share and contribute our research works in Rescue Robotics to support our Rescue Robot Research community.

APPENDIX A
TEAM MEMBERS AND THEIR CONTRIBUTIONS

Jackrit Suthakorn – Advisor
Songpol Ongwattanakul – Co-Advisor
Choladawan Moonjaita – Co-Advisor/ Team Leader
Sakol Nakdhamabhorn – Senior Member (Programming)
Chawaphol Direkwatana – Senior Member (Developer)
Rachot Phuengsuk – Senior Member (Electronics)
Shen Treratanakulchai – Senior Member (Electronics)
Preedipat Sattayasoonthorn – Senior Member (Electronics)
Peerapat Owatchaiyapong – Co-Team Leader (Developer)
Maria Chatrasing – Algorithm Developer
Nantida Nillahoot – HRI and Coordinator
Branesh Madhavan Pillai – Control System
Pittawat Thiuthipsakul – Sensing System
Korn Borvorntanajanya – Programming
Suwipat Chalongwongse – Mechanical Design

APPENDIX B
SYSTEM COST

The table below shows the approximate cost of a tele-operative rescue robot in our team.

TABLE II
COST FOR ROBOT PARTS IN BOTH ROBOTS

BART LAB Rescue Robotics (Thailand)			
Item	**Quality**	**Unit Price (USD)**	**Price (USD)**
Laser-Scanner	2	5,700	11,400
Computer Notebook	2	1,200	2,400
Camera	7	(avg.) 150	1,050
Thermal Camera	1	2,000	2,000
Sensor (system)	2	(est.) 500	1,000
Motor (Locomotion)	8	1,200	9,600
Motor (Manipulator)	7	800	5,600
Electronics	-	-	1,000
Mechanics	-	-	1,500
Part Machining/Misc.	-	-	3,500
Total			**39,500**

ACKNOWLEDGMENT

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REFERENCES

[1] S. Schwertfeger, J. Poppinga, K. Pathak, H. B¨ulow, N. Vaskevicius, and A. Birk, “Jacobs University,” RoboCup Rescue 2009, TDP, Graz, Austria, June 2009.
[2] T. Nakaya, “NuTech-R,” RoboCup Rescue 2009, TDP, Graz, Austria, June 2009
[3] R. Sheh, A. Milstein, C. Sammut, B. Hengst, G. Dissanayake, and J.V. Miro, “Team Casualty,” RoboCup Rescue 2009, TDP, Graz, Austria, June 2009.
[4] Copyright 2007-2010 (c) Jeff Brown - All Rights Reserved
[5] https://www.hokuyo-aut.jp/02sensor/07scanner/utm_30lx.html
[6] http://www.optris.com/thermal-imager-pi160
[7] https://www.sparkfun.com/products/13233