RoboCup Rescue Team Description Paper SGBot

Liu Dikai, Xu Yuecong, Luo Tianze, Chen Hailin, Wang Jingbin, Zhang Jinyan, Zhang Xinye, Zhou Lingjin

Info

Team Name:	SGBot
Team Institution:	Nanyang Technological University
Team Leader:	Liu Dikai
Team URL:	

RoboCup Rescue 2018 TDP collection:
https://robocup-rescue.github.io/team_description_papers/

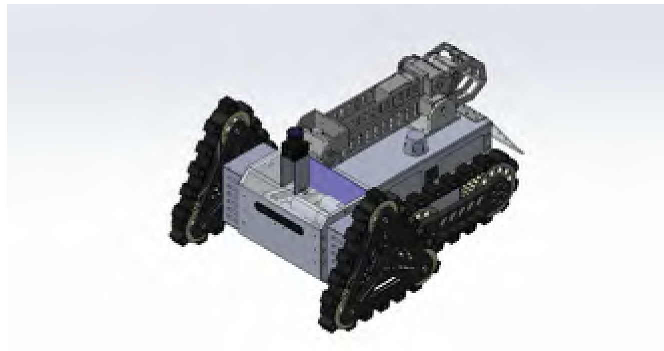
***Abstract*—This paper describes the mobile rescue robot developed by team SGBot for RoboCup Rescue Robot League. Our team focuses on small-sized autonomous system and the robot is designed to have the capability of fully on-board computation. To accomplish this ability, an embedded AI computing device and a mini PC are installed. Supported by stereo cameras, LiDAR, IMU and other sensors, rich environment data could be gathered, which will be used for computation of SLAM, path planning and object detection in real time. Equipped with triangular track wheels and a mechanical arm, the robot could explore and interact with the disaster environment. A web-based user interface will be developed for easily monitoring the system from any personal devices, like laptops and smart phones.**

***Index Terms*—RoboCup Rescue, Team Description Paper, UGV, Autonomous System, Artificial Intelligence.**

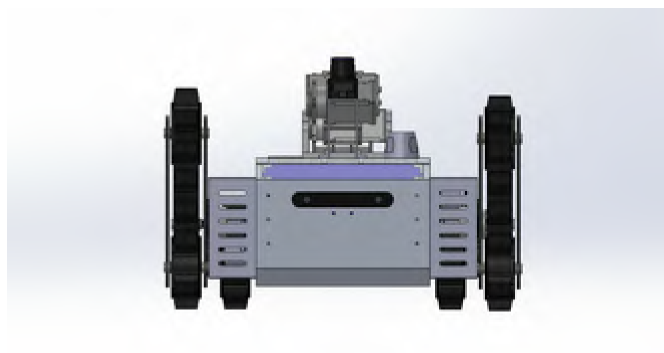
I. Introduction

TEAM SGBot was established under Innovation Lab, School of Computer Science and Engineering (SCSE), Nanyang Technological University (NTU), Singapore in Aug 2017 with the support from NVIDIA AI Technology Center (NVAITC). Driven by the goal of applying state-of-the-art artificial intelligence technology in robotics to build an autonomous urban search and rescue (USAR) robot, the team has designed an unmanned ground vehicle (Figure 1). The robot is still under developing and constructing currently. The participation in RoboCup Rescue Robot League competition would be an important milestone for the team and would be a great opportunity to test the robot.

SGBot is designed to satisfy the Small Robot requirement. Compact size and light weight give the robot maximum maneuverability. The front triangular track wheels help the robot to overcome obstacles easily by adjusting the angles of these wheels. Despite the small size, the on-board processing power is maximized with NVIDIA TX2 Developer Kit (Figure 2), an embedded AI computing unit [1], and Intel NUC, a mini computer. SGBot is designed to have the capability of conducting the tasks without any human interactions or any external devices. WiFi system is available for monitoring the robot states and allowing the operator to take over the control when necessary.



(a) Isometric View



(b) Front View

Fig. 1. Rendered image of SGBot

Cutting-edge AI technology is used to make the robot smarter to meet the autonomous control requirement. Deep neural networks are used for object recognizance, path planning and low-level control. The main focus point is to learn a general AI system for USAR robots under complex disaster environment.

Sensors like Stereo cameras, LiDAR and IMU are used to gather environment data for computations like 2D and 3D SLAM, object detection and autonomous control. All the data processing jobs could be done on-board with TX2 and NUC.

II. System Description

SGBot is a tracked wheel vehicle with a pair of triangular track wheels at the front. It is designed to be small and light-weighted for maximum maneuverability in complex disaster environment. The robot packs high performance mini computers for fully on-board autonomous computation capability.

Yonggang Wen is with School of Computer Science and Engineering, Nanyang Technological University, Singapore.
Jianxiong Yin is with NVIDIA.

Fig. 2. NVIDIA Jetson TX2 Developer Kit

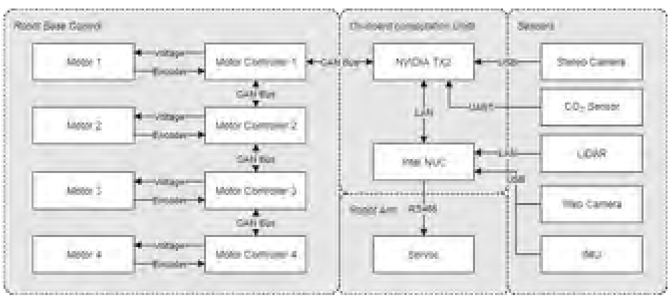


Fig. 3. Hardware structure

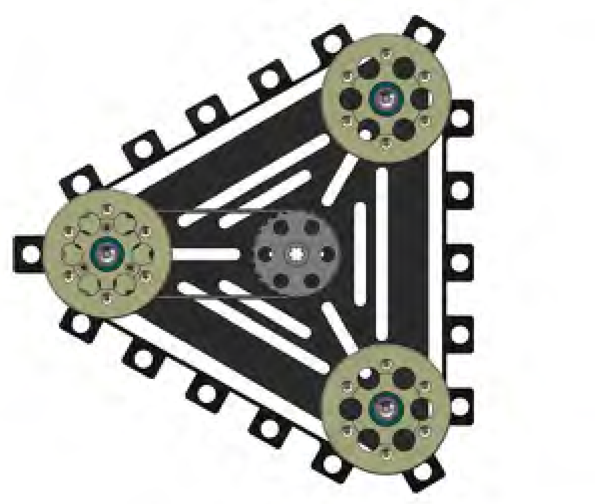
Fig. 4. Mechanical design of right side tracks

A. Hardware

The overall hardware structure is shown in Figure 3.

- Locomotion: The robot is driven by four FAULHABER motors. Two motors are each used to control the speed of left and right side tracks. The other two are used to control the rotation of the triangular track wheels while the robot is overcoming some obstacles. Figure 4 shows the mechanical design of the right side tracks.
  The design of the triangular track wheels is showed in

(a) Isometric View



(b) Inner parts

Fig. 5. Triangular track wheel

Figure 5. The track is driven by a pulley connected to the center pulley by belt. The inner frame is connected to a gear, which gives the control of the entire wheel. With a ball bearing inside the gear, the shaft can rotate freely and control the track speed. With this design, the rotation of the wheel and the speed of the track can be controlled separately.
- Power (Batteries): Since the voltage requirement of on-board devices are different, three rechargeable LiPo batteries, one 7-cells (29.4 V), one 4-cells (16.8 V) and one 3-cells (12.6 V), are used. Thus, no DC-DC converters with high current throughput are required.
- Electronics: The motors are equipped with high end encoders and motor controllers from FAULHABER to maximum the performance of the motors. The encoders have 1024 lines per revolution and each motor is controlled by one MC5010SCO motion controller, which is either in speed control mode or position control mode.
- Manipulation: The robot is equipped with one robot arm

Fig. 6. CAD drawing of robot arm

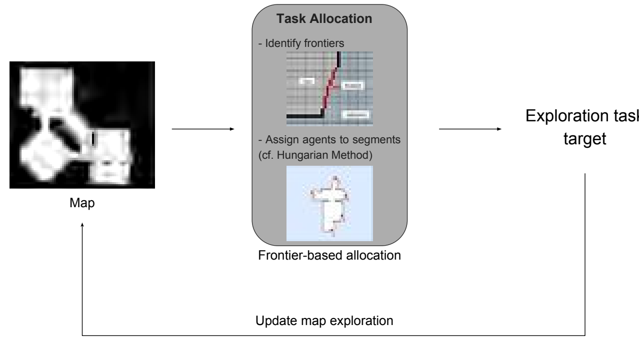


Fig. 7. Frontier based task allocation

for inspection and interaction with the environment. One web camera will be attached to the arm, so that it could explore the area unreachable. The gripper could perform some simple tasks. The robot arm is powered by smart servos, which has built in speed, position and torque control to archive high accuracy control.

- Sensors: Various sensors are equipped on the robot to gather rich environment data for data processing.
  - Stereo Camera: A ZED Stereo Camera is attached to the front of the robot to gather RGB-D information for 3D SLAM and object detection. The rich RGB-D data is ideal for mapping and segmentation, so that the robot could understand the environment and autonomously perform tasks. ZED provided high resolution image stream and accurate depth date.
  - LiDAR: Hokuyo UST-20LX is a small and light-weighted laser range finder, which is ideal for a compact robot like SGBot. It provides high end experience with a shorter detection range of 20m. For the terrain of disaster environment, the space would be compact and long range LiDAR could not give extra help. The data is used for 2D SLAM and fusing with the data from 3D SLAM for location and orientation estimation.
  - Inertial Measurement Unit: A 9 DoF PhidgetSpatial IMU is installed on the robot to get the orientation of the robot and the data will be fused with stereo camera and LiDAR to get better result.
  - CO_2 Sensor: An UART infrared CO_2 Sensor from DFRobot will be attached to the front of the robot to get the gas information of the surrounding.
- Computation: SGBot takes on-board computation power seriously and two mini computers are installed on-board.
  - Jetson TX2 Development Kit (Figure 2) The latest embedded AI supercomputer from NVIDIA gives the robot capability of on-board deep learning computation. Powers up the autonomous control and object detection, which are based on Deep neural networks pre-learned by the team. The GPIO pins are used for CAN Bus and UART connections with sensors and motor controllers.
  - Intel NUC7i7BNH Kit: High end mini computer from Intel for general purpose computation, like the pre-process of the data, 2D and 3D SLAM. A web UI is also hosed by the NUC for states monitoring and interacting with the robot.

B. Software

Refer to Table IV in the Appendix.

The software system is mainly based on ROS Kinetic for data sharing and co-processing between two computers.

- SLAM: The Simultaneous Localization And Mapping is a key problem for autonomous control. Since the terrain could be too complex to be simplified as a 2D map, RTAB-Map is used for generating 3D and 2D map in the same time. RTAB-Map is based on efficient memory management [2] that 3D and 2D SLAM can run simultaneous in real time with the on-board NUC.
- Path Planning: To autonomous pass through the terrain, an AI will be pre-trained first in simulator and later be transferred in real world training. Frontier based task allocation and Deep Q Network are mainly used in the training process.
  - Frontier based task allocation: It is an algorithm for overall path planning for navigational goals [3]. Based on Frontier Points allocation, the agent is assigned to reach the allocated Frontiers using Hungarian method and expand the map (Figure 7).
  - Deep Q Learning (DQN): A trending algorithm from Deep Reinforcement Learning and is known to train a general AI to play Atari [4]. Reinforcement learning brings machine learning in continuously control to another level and with a proper simulator, the robot could simply learn how to drive itself by itself. It is also used to train the control of the robot arm.
- Computer Vision: Deep neural networks are used to train the computer vision system to autonomously detect objects of interest and identify the class of the object in real time.

C. Communication

Since two computers are equipped on-board, a managed network switch is used for cross communication between these two devices. The LiDAR also uses a LAN interface and can be accessed by its IP address.

Most sensors are connected to the computers with USB for data communication. The motor controllers are connected with TX2 in an CANopen network for easy cable management and high efficiency communication. Servos on the robot arm are connected into a RS485 chain and connected to the NUC with a USB to RS485 converter.

TX2 will establish a WiFi connection at 5GHz using the IEEE 802.11ac standard to a UBITIQUI locoM5. Thus, the robot LAN network can be accessed by any device in the same WiFi network for monitoring and control purpose.

D. Human-Robot Interface

A web based server will be hosted as a ROS node with the support of JavaScript, which allows any devices in the same network to access the data and control of the robot. Two video streams from the stereo cameras and the web camera will be available with the masks generated by the detection function. Live 2D and 3D map, sensor readings and other important data can be easily access through the web server.

The ground station will be equipped with a monitor, a laptop, keyboard and gamepad, so that the robot can be controlled manually by the operator when necessary. For better control and monitoring experience, the ground station will run a Qt based GUI. GUI tools from ROS, like rviz, will be used to visualize the data.

III. Application

A. Set-up and Break-Down

The robot is designed to be a compact and light-weighted system that can be easily carried by 2 people.

The control station is designed to be packed into a protector tool case for easy carrying and setup.

To start a mission, the robot and the laptop need to be switched on and connect to the same WiFi network.

B. Mission Strategy

As the main focus point of the team is to build a fully autonomously UGV, the robot will be set to run autonomously by default. Teleoperation will only be used when the autonomously control failed.

C. Experiments

Since the robot is still under developing and constructing, it is only tested under the simulator. With the currently trained AI, the robot still have the room for improvement. After archiving a satisfied result in the simulator after more training, real world testing will be conducted.

IV. Conclusion

During the past half a year, team SGBot started from scratch. In this paper, currently design concept and mission strategy is discussed. Although the robot will not be ready until the end of this month, the simulator result is getting better with more training.

TABLE I
MANIPULATION SYSTEM

Attribute	Value
Name	SGBot
Locomotion	tracked
System Weight	45kg
Weight including transportation case	-
Transportation size	-
Typical operation size	0.6 x 0.6 x 0.4 m
Unpack and assembly time	-
Startup time (off to full operation)	-
Power consumption (idle/ typical/ max)	- / - / -
Battery endurance (idle/ normal/ heavy load)	- / - / -
Maximum speed (flat/ outdoor/ rubble pile)	- / - / -
Payload (typical, maximum)	- / -
Arm: maximum operation height	100 cm
Arm: payload at full extend	1kg
Support: set of bat. chargers total weight	2.5kg
Support: set of bat. chargers power	1,000W (100-240V AC)
Support: Charge time batteries (80%/ 100%)	- / -
Support: Additional set of batteries weight	3kg
Cost	40000 SGD

TABLE II
OPERATOR STATION

Attribute	Value
Name	Operation Station
System Weight	5kg
Weight including transportation case	5kg
Transportation size	1 x 0.4 x 0.2 m
Typical operation size	1 x 0.4 x 0.2 m
Unpack and assembly time	1 min
Startup time (off to full operation)	5 min
Power consumption (idle/ typical/ max)	80 / 100 / 110 W
Battery endurance (idle/ normal/ heavy load)	- / - / -
Cost	2000 SGD

Attending RoboCup Rescue Robot League would be a great chance for us to validate our robot and would be an important milestone of our team.

Appendix A
Team members and Their Contributions

- Liu Dikai — Team leader, autonomous system
- Xu Yuecong — Autonomous system
- Luo Tianze — Autonomous system
- Wang Jingbin — Mechanical design
- Zhou Lingjin — Mechanical design
- Chen Hailin — Computer vision
- Zhang Xinye — Computer vision
- Zhang Jinyan — Web UI

Appendix B
Lists

A. Systems List

Refer to Table I and II.

The robot is still under building, thus some data is not confirmed yet.

B. Hardware Components List

Refer to Table III

TABLE III
HARDWARE COMPONENTS LIST

Part	Brand & Model	Unit Price	Num.
Drive motors	FAULHABER 3890H024CR		2
	FAULHABER 3242G024CR		2
Drive gears	Planetary Gearheads 38A 45:1		2
	Planetary Gearheads 38A 480:1		2
Drive encoder	Incremental Encoder IE3-1024L		4
Motor drivers	Motion Controllers MC5010SCO		4
DC/DC	20W Adjustable DC-DC	USD 4.90	1
Batteries	LiPo 7S1P 5100mAh	SGD 116.82	1
	LiPo 4S1P 4000mAh	SGD 48.60	1
	LiPo 3S1P 6000mAh	SGD 72.90	1
Computing Unit	Jetson TX2 Developer Kit		1
	Intel NUC7i7BNH	SGD 1279.72	1
WiFi Adapter	locoM5	SGD 99.00	1
Siwtch	tp-link TL-SG105E	SGD 40.00	1
IMU	PhidgetSpatial 3/3/3	SGD 257.00	1
Cameras	Logitech C170	SGD 32.00	1
Stereo Camera	ZED Stereo Camera	USD 499.00	1
LRF	Hokuyo UST-20LX	SGD 2996.00	2
CO_2 Sensor	UART Infrared CO2 Sensor	SGD 141.17	1
Robot Arm	DYNAMIXEL MX-106R	USD 493.90	2
	DYNAMIXEL MX-64R	USD 305.90	3
	DYNAMIXEL MX-28R	USD 225.90	2
	DYNAMIXEL U2D2	USD 49.90	1

TABLE IV
SOFTWARE LIST

Name	Version	License	Usage
Ubuntu	16.04	open	
ROS	Kinetic	BSD	
PCL [5]	1.7	BSD	ICP
OpenCV [6], [7]	2.4.8	BSD	Haar: Victim detection
OpenCV [8]	2.4.8	BSD	LBP: Hazmat detection
RTAB-Map [9]	0.3.4	BSD	2D and 3D SLAM
V-Rep	3.4.0	Non-limited EDUCATIONAL	Simulator

C. *Software List*

Refer to Table IV.

ACKNOWLEDGMENT

The authors would like to thank NVIDIA AI Technology Center and School of Computer Science and Engineering, Nanyang Technological University, Singapore for making this project possible.

The authors would like to express their thanks to FAULHABER, MiSUMi and Hokuyo for sponsoring and supporting this project.

REFERENCES

[1] D. Franklin. (2017, 3) NVIDIA Jetson TX2 Delivers Twice the Intelligence to the Edge. [Online]. Available: https://devblogs.nvidia.com/jetson-tx2-delivers-twice-intelligence-edge/

[2] M. Labb and F. Michaud, "Memory management for real-time appearance-based loop closure detection," in *Intelligent Robots and Systems (IROS), 2011 IEEE/RSJ International Conference on*. IEEE, 2011.

[3] O. S. Jan Faigl and F. Charpillet, "Comparison of task-allocation algorithms in frontier-based multi-robot exploration," in *Multi-Agent Systems. EUMAS 2014*, ser. Lecture Notes in Computer Science. Springer, Cham, 2015, vol. 8953. [Online]. Available: https://doi.org/10.1007/978-3-319-17130-2_7

[4] V. Mnih, K. Kavukcuoglu, D. Silver, A. Graves, I. Antonoglou, D. Wierstra, and M. Riedmiller, "Playing Atari with Deep Reinforcement Learning," *ArXiv e-prints*, Dec. 2013.

[5] R. B. Rusu and S. Cousins, "3D is here: Point Cloud Library (PCL)," in *IEEE International Conference on Robotics and Automation (ICRA)*, Shanghai, China, May 9-13 2011.

[6] P. Viola and M. Jones, "Rapid object detection using a boosted cascade of simple features," in *Computer Vision and Pattern Recognition, 2001. CVPR 2001. Proceedings of the 2001 IEEE Computer Society Conference on*, vol. 1, 2001, pp. I–511–I–518 vol.1.

[7] R. Lienhart and J. Maydt, "An extended set of haar-like features for rapid object detection," in *Image Processing. 2002. Proceedings. 2002 International Conference on*, vol. 1, 2002, pp. I–900–I–903 vol.1.

[8] S. Liao, X. Zhu, Z. Lei, L. Zhang, and S. Li, "Learning multi-scale block local binary patterns for face recognition," in *Advances in Biometrics*, ser. Lecture Notes in Computer Science, S.-W. Lee and S. Li, Eds. Springer Berlin Heidelberg, 2007, vol. 4642, pp. 828–837. [Online]. Available: http://dx.doi.org/10.1007/978-3-540-74549-5_87

[9] M. Labb and F. Michaud, "Long-term online multi-session graph-based splam with memory management," *Autonomous Robots*, 2017.