# RoboCup Rescue 2017 Team Description Paper SHINOBI

Takemori Tatsuya, Suatac Baris, Kawai Yuta, Maeda Ryuuma, Yoneda Hiroki, Tianyu Wen and Mintaek Oh

**Info**

| | |
|---|---|
| Team Name: | SHINOBI |
| Team Institution: | MatsunoLab, Kyoto University |
| Team Leader: | Takemori Tatsuya |
| Team URL: | http://www.mechatronics.me.kyoto-u.ac.jp/ |

RoboCup Rescue 2017 TDP collection:
http://wiki.robocup.org/Robot_League

***Abstract*—This paper explains details of the robot FUHGA which was designed to participate in RoboCup 2017 competition. The SHINOBI rescue robotics team consists of students that are studying in Matsuno Laboratory, Kyoto University, Japan.**

***Index Terms*—RoboCup Rescue, Team Description Paper, SHINOBI, FUHGA.**

## I. Introduction

THE SHINOBI rescue robotics team consists of Master's degree students that are studying in Matsuno Laboratory, Kyoto University, Japan. It consists of seven members. SHINOBI has developed several robots in the past and tested its robots in both real disaster areas and competitions. The prizes that the team won are RoboCup 2002 (Fukuoka City) second place, RoboCup Japan Open Rescue Robot League first place, RoboCup Japan Open (Osaka) first place, RoboCup 2004 advanced to finals (5th), RoboCup 2006 Rescue Robot League Locomotion Challenge 1st place, RoboCup Japan Open 2007 (Numazu City) 2nd place, RoboCup 2007 (USA-Atlanta) Best in Mobility 2nd place, RoboCup Japan Open 2009 (Osaka) Rescue Actual League 1st place, Robocup 2009 (Austria Graz) 4th overall 3rd in mobility, RoboCup Japan Open 2010 Rescue Robot Actual League Measurement Automatic Conference Award, Thailand Rescue Robot Championship 2010 best autonomous award, RoboCup Japan Open 2011 best in class autonomy, RoboCup Japan Open 2012 1st place, RoboCup Japan Open 2014 1st place, RoboCup Japan Open 2015 Best in class autonomy, RoboCup Japan Open 2016 Best in Class Autonomy.

SHINOBI's previous robots have been innovative in the area of rescue robotics. For example KOHGA [3] is a snake-like robot that has crawlers on its every link. The SHINOBI team, over the years, made 2 new models of KOHGA. The third model, KOHGA3, is a robot that has four flippers for mobility. KOHGA3 has been one of the biggest inspirations in design. The aim of the SHINOBI team for this competition is to build a robot that can be both tele-operated and autonomous, that can be used for search and rescue missions, has high mobility and good understanding of its environment. The main tasks were to make the robot durable and modular in the sense that it can move in many different terrains, good manipulation ability and was to generate a map of its environment and understanding the dangers around it. To achieve these tasks, the robot has been equipped with several sensors and the mechanical design was built accordingly. The sensors for understanding the environment are: cameras, CO2 sensor, thermal camera and Kinect. The mechanics of the robot consists of two categories. One is the mobility. Four people from the SHINOBI Team has been assigned to design the mobility. The aim of the Mobility Team was to make the main body of the robot highly mobile, as light as possible and very durable. The robot has two flippers and two body crawlers to move. The second category was the Arm. The Arm group consisted of two people and their task was to build the manipulator and the gripper. The arm team has built a seven degrees of freedom manipulator with a gripper attached to it as an end-effector. We also wanted to make the manipulator help robot moving over obstacles by adding it a passive wheel.

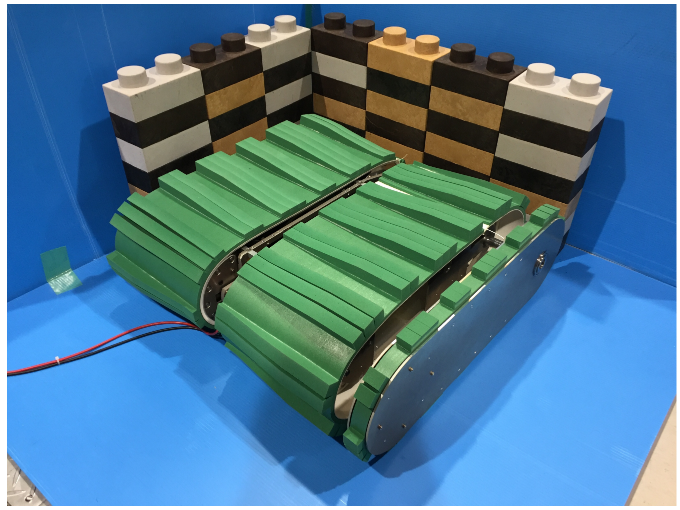

Fig. 1. Photo of the robot. The arm has not been assembled yet. Blocks on the background are 15.5 cm in length, 7.5 cm in width and 5 cm in height.

In conclusion, SHINOBI Team has built a robot that has high mobility and has a good sense of its environment. Over ten years, SHINOBI Team has the experience of building rescue robots caring for real disasters. This experience helped us predict the possible problems beforehand and helped us

Takemori Tatsuya, Suatac Baris, Kawai Yuta, Maeda Ryuuma, Yoneda Hiroki, Tianyu Wen and Mintaek Oh are with the Kyoto University, Graduate School of Engineering, Department of Mechanical Engineering and Science, Mechatronics Laboratory.

avoid unexpected results. We have been inspired with our previous robots and integrated our new ideas into the new robot FUHGA.

### A. Improvements over Previous Contributions

By analysing the robots we have used in previous RoboCup Rescue competitions, we decided to come up with a new robot. From the experiences our team has obtained we decided to change/improve the concept.
The concept of FUHGA is high mobility. To achieve this, we mainly focused on two characteristics; arm and full body sponge crawler.
PIAP GRYF[1] is an explosive ordnance disposal robot, which is characterized by its manoeuvrability. Because of its light body and relatively large arm, the robot can overcome the step higher than its height using its arm. However, PIAP GRYF's main body is not fully covered by body crawler. This may cause it to get stuck in uneven fields. Full body crawler is known to have good performance for traverse rough terrain, since the crawler can touch to the ground. Now, a rescue robot called Quince[2] which has body crawlers, is used for inspection of nuclear power plants after Great East Japan Earthquake.
For our robot, we designed a strong arm with a passive wheel to help mobility and full body sponge crawler for better travelling performance. In addition, we use sponge for crawler rather than rubber. Sponge can adaptively fit to obstacles and rough terrains and increases the traction.

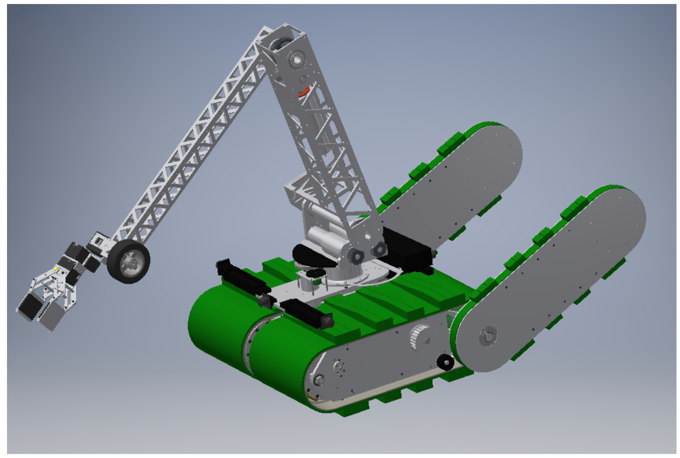

Fig. 2. The structure of the whole robot can be seen. In this figure, flippers are lifted up to make them more visible. The green parts on the main body and flippers are sponges.

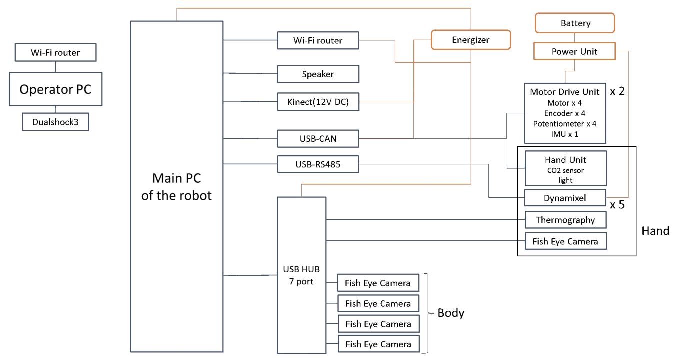


Fig. 3. Hardware structure

## II. System Description

### A. Hardware

The hardware structure is shown in Fig 3.

- Locomotion
  FUHGA has high mobility thanks to its body crawlers, flippers and manipulator which consists of a passive wheel. Each body crawler driven by a DC motor (Maxon, 24V, 150W) is approximately 230 mm in width, which reduces the possibility of getting stuck. They are made of sponge that makes FUHGA robust against impacts. The long flippers, which are almost the same length as the body length will help overcoming large obstacles. The flipper angle is driven by a DC motor on each flipper (Maxon, 24V, 150W). We use the manipulator for high mobility as well. The advantages of the manipulator are twofold; one is the arm part which can improve mobility, and the other is the gripper part to manipulate objects. The arm part is designed so that it can support the main body when the robot needs to get over a high step or cross a huge gap which cannot be handled with flippers alone. In order to achieve this goal, we use four DC motors with high torque capacity (one : Maxon, 24V, 90W, the others : Maxon, 24V, 150W); one for the elbow pitch joint, two for base pitch joint, and one for base roll joint (see Fig. 5). On the tip of the arm, we have a passive wheel. The gripper part is described in the next subsection.
- Manipulation
  In order to manipulate objects, FUHGA has a gripper that is actuated by identical servo motors (Dynamixel XM430-W350-R) on the tip of the arm. The wrist has three joints (pitch, yaw, and roll, respectively) and gripping fingers are designed as a parallel-link mechanism (see Fig. 6).
- Batteries
  We use Hyperion G6 HV 30-60C 5200mAh 6S battery.
- Sensors and Cameras
  Each DC motor; two for the body crawlers, two for the flippers, and four for the arm, has an encoder. In addition, each joint of the arm and flipper has a potentiometer to measure the angle. On the base of the arm, we have four fish-eye cameras MCM-4350FISH for front, back, right and left direction. Additionally, Kinect v2 actuated by a servo motor to look at left and right is equipped on the base to create a map of the environment. The gripper has a $CO_2$ sensor Figaro CDM7160, thermal camera PI-160, and a fish-eye camera so that it can see narrow areas by inserting the gripper. For inertial measurements and the attitude of the robot, we use MPU-6000 6 axis IMU.

### B. Software

Refer to Table IV in the Appendix.

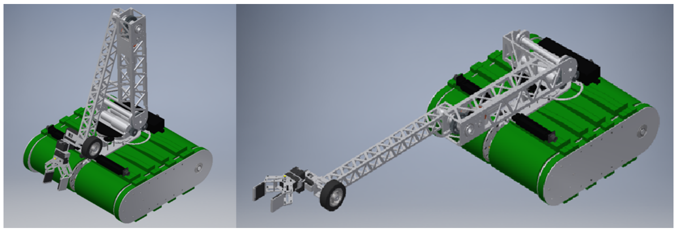

Fig. 4. On the left, you can see the robot with its smallest possible size. Meanwhile, on the right side, robot with maximum size can be seen

Both the PC installed in the robot and the PC of the operator station use Ubuntu 14.04.
Meanwhile, ROS Indigo is used as the software development platform. MCUs are installed in each module on the robot, and each MCU performs local processing. For example, the MCU on the motor driver unit acquires and processes sensor values from the encoder and potentiometer, and controls so that the angular velocity of the motor converges to the target value. Based on information gathered from each module and device, the main PC in the robot creates a 3D CG model of the robot and creates a 3D map. The manipulator calculates and controls the joint angle that realizes the target position of the gripper using inverse kinematics.

### C. Communication

Communication between the operator station and robot is done using wireless LAN. For this communication, Contec FXE-2000 and FXE-1000 which are radio equipments conforming to IEEE 802.11n/a/b/g has been used. FX-ANT-A10 is used for the master unit antenna, and FX-ANT-A7 is used for the slave unit antenna.

### D. Human-Robot Interface

To input tele-operation Sony Dualshock 3 and touch screen are used. Five fisheye cameras are mounted on the robot, and operators can switch images to be displayed larger if necessary. Since the position of the tip of the manipulator is controlled by inverse kinematics, the operator can operate with intuitive input. We create a 3D map with SLAM using Kinect v2 and display it for remote operation. The 3DCG model reflecting the posture of the robot, the angle of the flipper, and each joint angle of the arm is displayed. It also displays information on thermal camera, microphone, and CO2 sensor.
To get used to the robot, the operator conducted basic training of manoeuvring using simulations and then practised using real machine. In particular, we practised by reproducing slalom, stairway, and random step environments.

## III. Application

### A. Set-up and Break-Down

In order to shorten the time of Set-up and Break-Down, we put together a laptop PC, sub display, game pad, antenna etc in one case. You can build an operator station by carrying a single case and opening it.

### B. Mission Strategy

The strategy for this year was mostly about the mechanical design of the robot. We designed a robot that has high mobility even on rough surfaces. At the same time, we tried to make the robot light and strong, which helps relatively huge effect of arm for mobility. Our main strategy is inspection by using sensors on the hand, then running through various kind of field by tele-operation.

### C. Experiments

For experiments, we did not have much time to test the robot. We have tested the robot's mobility on smooth surface after the first assembly. Unfortunately, we have not yet built any standard test methods for the robot. However, in upcoming days we will build some test areas. We have learned from our small test that the robot had some friction problems between its rollers and the crawlers. One of the rollers' rubber part did not create a lot of friction with the crawler so that when the robot was doing pivot turn, the crawler was slipping.

### D. Application in the Field

We have developed several rescue robots previously and some of them have been used for inspection in buildings affected by huge earthquakes. We have gathered information from disaster areas which were too dangerous for humans to enter. Our new robot, FUHGA, has higher performance in mobility than our previous ones due to the fact explained above. Therefore, we believe that FUHGA will be more useful in disaster-affected areas because it has the ability to climb high steps or cross over large gaps which our previous robots did not have the ability to.
We will improve our robot for better use by reducing the robot weight, changing or adding robot parts for better sand-proofing.

## IV. Conclusion

In conclusion, as a team with a background of more than 10 years, we believe that we have built a robot that is better than previous ones in the case of mobility and sensing its environment. Learning from previous experiences, failures and talking to previous members of the SHINOBI, we had a good understanding of what to do from the beginning and we worked hard for it.
Until now, we still have not finished the whole robot. Even though the design of the robot is finished, we still have improvements to do about SLAM, programming and manipulation. After these improvements, robot will be ready to compete in RoboCup 2017. This is also the reason for the lack of detailed experiments. Therefore, we would like to work hard and finish the robot as soon as possible.

## Appendix A
## Team members and Their Contributions

- Takemori Tatsuya programming, communication, electronics, control, team leader
- Suatac Baris mobility design, gripper design

- Kawai Yuta mobility design
- Maeda Ryuuma manipulator design and control
- Yoneda Hiroki mobility design, interface, sensors
- Tianyu Wen gripper design, interface
- Mintaek Oh mobility design

## APPENDIX B
## CAD DRAWINGS

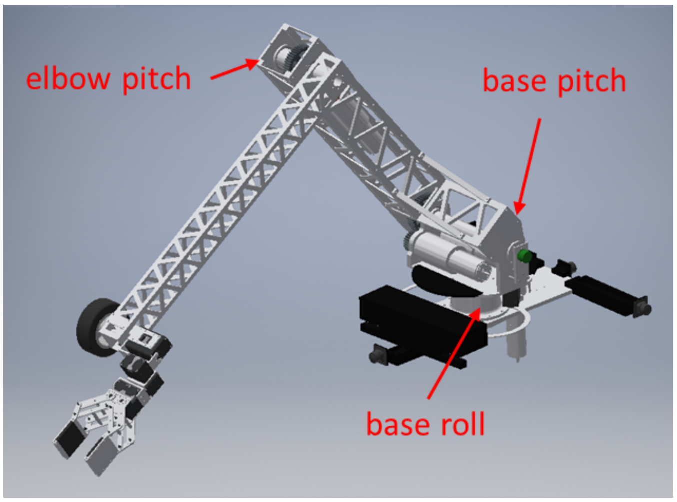


Fig. 5. The manipulator of FUHGA consists of arm with 3-DoF and gripper with 3-DoF

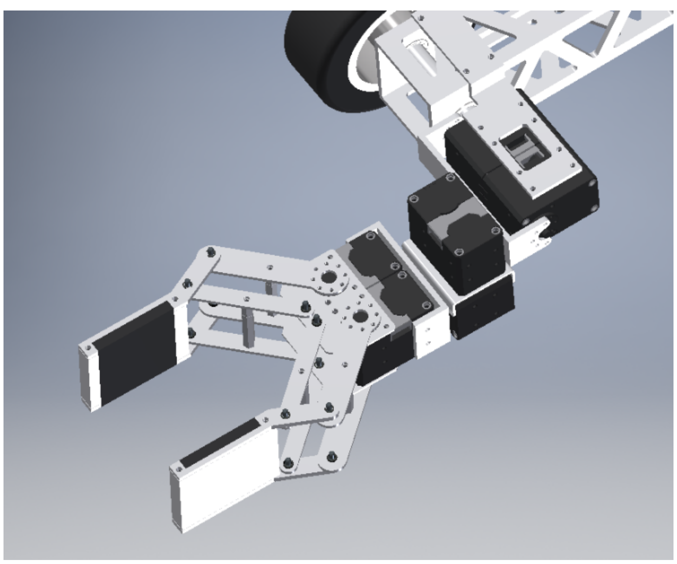

Fig. 6. The hand has 3-DoF wrist and fingers actuated with parallel-link mechanism

## APPENDIX C
## LISTS

### A. Systems List

For the operator station, please refer to Table II.

TABLE I
MANIPULATION SYSTEM

| Attribute | Value |
|---|---|
| Name | FUHGA |
| Locomotion | Tracked |
| Setup time | 10 min |
| Maximum Speed (flat, 45 deg slope) | 0.5 / 0.2 m/s |
| Weight (including Manipulator) | 42 kg |
| Size | W : 0.6 × H : 0.9 × L :0.6 m ( Fig 4 (left))<br>W : 0.6 × H : 0.4 × L :1.44 m ( Fig 4 (right)) |
| Manipulator Weight | 14.5 kg |
| Max. operation height | 1.5 m |
| Upper Arm Length | 0.5 m |
| Fore Arm Length | 0.6 m |
| Base Size | $0.31 \times 0.13m^2$ |
| Wheel Diameter | 0.1 m |
| Base Roll's Max. Continuous Torque | 41.3 Nm |
| Base Roll's Rotational Speed | 8.9 rpm |
| Base Pitch's Max. Continuous Torque | 130.1 Nm |
| Base Pitch's Rotational Speed | 10.9 rpm |
| Elbow Pitch's Max. Continuous Torque | 65.0 Nm |
| Elbow Pitch's Rotational Speed | 10.9 rpm |
| Gripper Length (Root Joint to Fingertip) | 0.22 m |
| Gripping Force | 33.5 N |
| Cost | 20000 USD |

TABLE II
OPERATOR STATION

| Attribute | Value |
|---|---|
| Name | FUHGA-OP |
| System Weight | 5kg |
| Weight including transportation case | ?kg |
| Transportation size | ? m |
| Typical operation size | 0.5 x 0.4 x 0.4 m |
| Power consumption (idle/ typical/ max) | ? / ? / ? W |
| Battery endurance (idle/ normal/ heavy load) | ? / ? / ? h |
| Any other useful attribute | Touch screen |
| Cost | 2500 USD |

TABLE III
HARDWARE COMPONENTS LIST

| Component | Brand&Model | Unit Price(USD) | Num. |
|---|---|---|---|
| Drive motors | Maxon RE40 150W | 290 | 2 |
| Drive gears | Maxon Planetary Gearhead GP52C | 296 | 2 |
| Drive encoders | Maxon Encoder HEDS 5540 | 78 | 2 |
| Flipper motor | Maxon RE40 150W | 290 | 2 |
| Flipper gears | Maxon Planetary Gearhead GP52C | 307 | 2 |
| Flipper encoders | Maxon Encoder HEDS 5540 | 78 | 2 |
| Flipper potentio meters | Midori Precisions CP-2F | 43 | 2 |
| Arm motors | Maxon RE40 150W | 290 | 3 |
| | Maxon RE35 90W | 221 | 1 |
| | Dynamixel XM430-W350 | 186 | 6 |
| Arm gears | Maxon Planetary Gearhead GP52C | 307 | 3 |
| | Maxon Planetary Gearhead GP42C | 244 | 1 |
| Arm encoder | Maxon Encoder HEDS 5540 | 78 | 4 |
| Potentio meter | Midori Precisions CP-2F | 43 | 4 |
| Batteries | Hyperion G6 HV 30-60C 5200mAh 6S | 122 | 1 |
| | Energizer XP18000A | 148 | 1 |
| Computing Unit | NUC6I5SYK | 415 | 1 |
| Wifi Router | CONTEC FXE1000 | 435 | 2 |
| IMU | Invensense MPU-6000 | 9 | 2 |
| Cameras | Micro Vision MCM4350FISH | 235 | 5 |
| | Microsoft Kinect v2 | 131 | 1 |
| CO2 Sensor | Figaro CDM7160 | 104 | 1 |
| Thermal Camera | Optris PI-160 | ? | 1 |
| Cost | Total | 9603 | |

TABLE IV
SOFTWARE LIST

| Name | Version | License | Usage |
|---|---|---|---|
| Ubuntu | 12.04 | open | |
| ROS | indigo | BSD | |
| OpenCV | 3.1 | BSD | Haar: Victim detection |
| Application for FUHGA | 1.0 | closed source | |

### *B. Hardware Components List*

For hardware components, please refer to table III.

### *C. Software List*

For software list, please refer to Table IV.

## ACKNOWLEDGMENT

The authors would like to thank machine shop of Kyoto University Katsura Campus for their help in machining the parts we need. We also would like to thank the previous members of SHINOBI Team and Tamura Hiroshi for their precious advice.

## REFERENCES

[1] PIAP, http://www.antiterrorism.eu/

[2] Keiji Nagatani, S. Kiribayashi, Y. Okada, et al., “Redesign of rescue mobile robot Quince,” *Proc. IEEE Int. Symp. Safety, Security Rescue Robot.*, 2011.

[3] Tetsushi Kamegawa, T. Yamasaki, H. Igarashi and F. Matsuno, “Development of the Snake-Like Robot ”KOHGA”,” *Proc. IEEE Int. Conf. on Robotics & Automation.*, 2004.