RoboCup Rescue 2023 Team Description Paper NITRo

Kotaro Kanazawa, Hayato Matsuo, Sota Sumikama, and Noritaka Sato

Info

Team Name:	NITRo
Team Institution:	Nagoya Institute of Technology
Team Country:	Japan
Team Leader:	Kotaro Kanazawa
Team URL:	https://github.com/SatolabNIT

***Abstract*—NITRo is a laboratory team from the Nagoya Institute of Technology that has been developing rescue robots and participating in competitions such as RoboCup since 2013. This year, the team develop a new quadrupedal robot, Kamuy2, equipped with manipulators. The hardware is almost complete, but the software is still in the development phase. Ultimately, the aim is to enable the robot to traverse uneven terrain, work with manipulators on uneven terrain, create 3D maps with sensors and collect various types of information.**

***Index Terms*—RoboCup Rescue, Team Description Paper, Quadruped robot, Manipulator, Teleoperation.**

I. Introduction

NITRO is a team composed of students belonging to a laboratory at Nagoya Institute of Technology. The advisor, Associate Professor Sato, was a member of SHINOBI as a student and participated in the RoboCup World Championships from 2003 to 2009. As for NITRo, it has been continuously developing various robots and participating in competitions since its first participation in the RoboCup Japan Open in 2012, aiming to expand the use of rescue robots by improving their performance. Below is a list of competitions in which NITRo has participated and the robots that have participated.

- In RoboCup Japan Open 2014, ”NITRo-Clawler”, a crawler-type robot with a manipulator, won 2nd place.
- In RoboCup Japan Open 2015, ”ACCESS+”, an autonomous robot, won Best-in-Class Autonomy.
- In RoboCup Japan Open 2016, the team won 4th place and Best-in-Class Mobility.
- In the RoboCup World Championship 2017, the team participated with ”GOLEG”, a legged robot with wheels.
- In the RoboCup World Championship 2018, the team participated with ”Hitro”, a small crawler robot.
- In RoboCup Japan Open 2018, ”Hitro” won Best-in-Class Autonomy.
- We participated World Robot Summit 2018 in Tokyo and 2021 in Fukushima.
- In RoboCup Worldwide 2021 on online, the team won first place in Aerial Operator.
- In RoboCup Asia-Pacific 2021, the team won 2nd Place and Best in Class Mapping with ”Imax”, a crawler robot with a 2-meter-long manipulator.

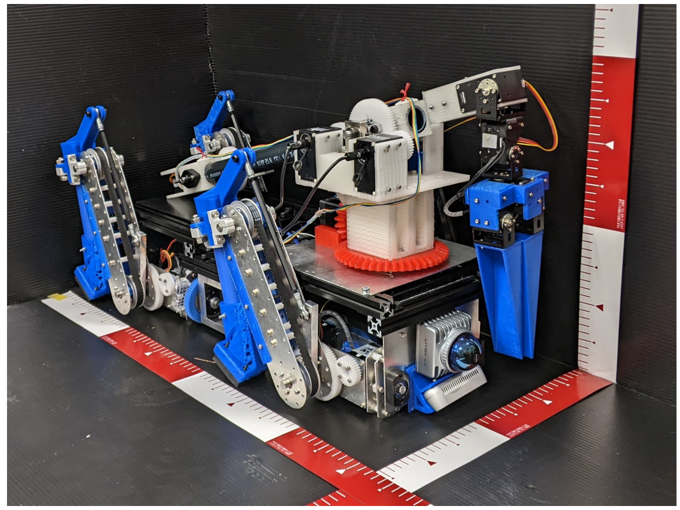

Fig. 1. A Image of Legged Rescue Robot Called ”Kamuy2”(One scale means 1cm)

As a student-driven team, the members change every few years, but they aim to further improve their skills by passing on their knowledge based on the techniques they have developed in the laboratory and the experience they have gained from participating in competitions.

For this year’s competition, the team developed a new quadruped robot, ”Kamuy2”, equipped with manipulators. in addition to the mobility of its quadruped, Kamuy2 has a 6-DOF manipulator mounted on the upper part of its body, allowing it to operate with a high degree of freedom. The 3D-LiDAR mounted on the vehicle body enables 3D mapping. In addition, multiple cameras, thermal imaging cameras, and inertial sensors contribute to remote exploration and numerous informational interfaces.

A. Improvements over Previous Contributions

Last year, we competed in the RoboCup Asia Pacific (RCAP) 2021 Aichi with our crawler rescue robot called Imax. This time, we have developed a new quadruped robot, Kamuy2, so the robot’s hardware has been completely redesigned, but the systems such as thermal imaging, hazard detection, communication and interfaces have been inherited. Kamuy2 is equipped with two 3D LiDARs, allowing it to create 3D maps, which was not possible with Imax.

B. Scientific Publications

In 2021, our team developed a crawler rescue robot called ”Imax”. We used Imax to compete in the World Robot Summit

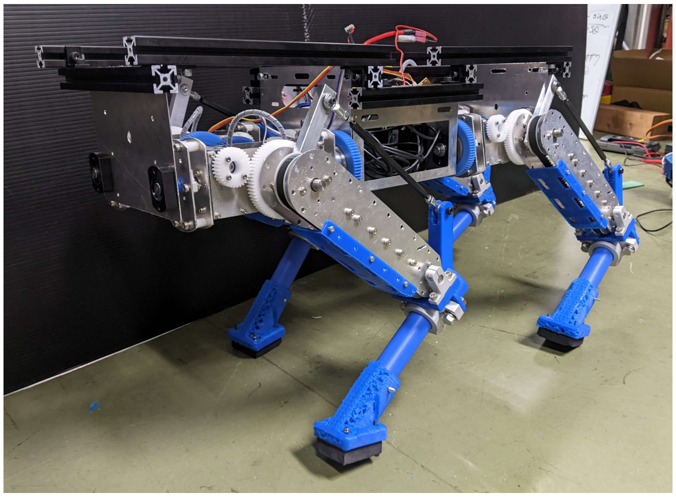

Fig. 2. Standing Pose

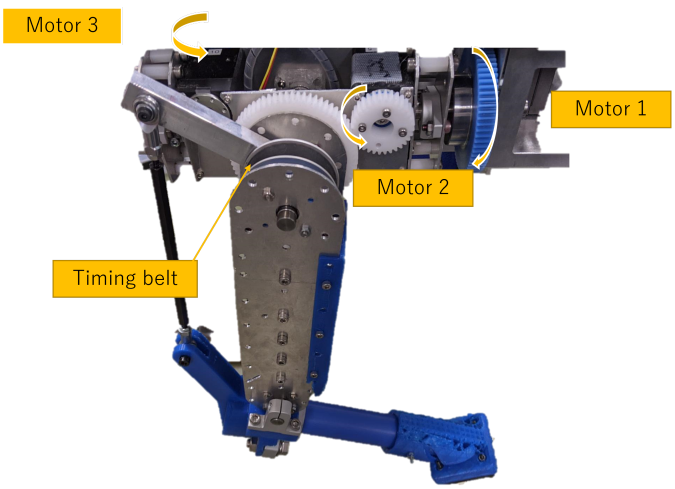

Fig. 3. Mechanism of Single Leg

(WRS) 2020 Fukushima and RoboCup Asia Pacific (RCAP) 2021 Aichi, where we improved the hardware and software[1].

II. System Description

A. Hardware

1) Leg Mechanism: Kamuy2 moves on four legs (Fig.2). The leg mechanism is equipped with a total of 12 DYNAMIXEL servo motors. All motors have a reduction ratio of 2.17x, which provides sufficient torque to support 20 kg. Each leg has three joints (Fig.3). To reduce the weight of the legs, all motors are located in the fuselage and the third link is driven by a timing belt installed inside the first link.

2) 6-DOF Manipulator: The kamuy2 is equipped with a 6-DOF manipulator consisting of nine DYNAMIXEL servomotors. Servo motors in the first and second links control the 1.8 m long manipulator by a reduction ratio of 2.17x. The end-effector is equipped with a gripper and a camera, which can be used to grip the object with the two DYNAMIXEL servomotors or to insert the object into a confined space for internal observation. The second link is also equipped with a

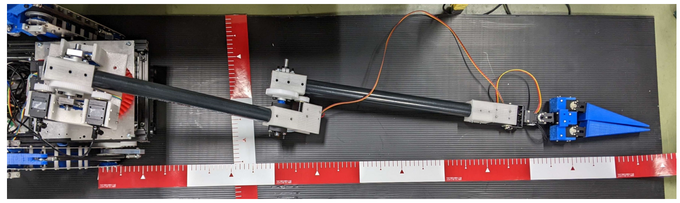

Fig. 4. Manipulator Mechanism

USB camera with a wide viewing angle, allowing a bird's-eye view of the robot body and the surrounding environment.

3) Sensors: Two depth cameras will be used: the first will be mounted on the manipulator's end-effector to measure the distance to the object. It will also be mounted on the front of the body to recognise the terrain ahead and control the legs. Two LiVOX MID-360 will also be mounted on the body to generate 3D maps. The IMU also detects body inclination. In addition, thermal cameras can search for heat sources.

4) Battery Resources: The PC is powered by a mobile battery, providing 19 V. Two 12 V 6600 mAh LiPo batteries are used for the robot's motors.

B. Software

Refer to Table IV in the Appendix.

1) Low Level Control: The power supply monitoring circuit warns if a voltage occurs. If a power failure occurs, the relay can be shut down remotely via the interface's GUI.

2) Leg Control: KAMUY2 moves its four legs by controlling 12 servo motors. For the control of the legs, only simple trot-walks using inverse kinematics are currently implemented. These are written in home-made source code, but we are also considering using open source packages. In the future, we are also considering the use of IMU, which controls the body's centre of gravity and adds fall prevention, and 3D-Lidar, which controls walking according to the terrain.

3) Manipulator Control: Nine motors are used for the manipulators. The inverse kinematics of the end-effectors are from the open source package Moveit! The PID gain is also adjusted for each link. In addition, the end-effector grippers are current-controlled to ensure a firm grasp.

4) Simultaneous Localization and Mapping(SLAM): We use RTAB-Map, an open source SLAM library.The map we actually made with RTAB-Map is shown in Fig.5.The grid in the figure is spaced 10 meters apart, which allows for high accuracy even in very large environments.It is also effective when processing large amounts of data and has a fast loop detection algorithm.

5) Recognize Objects: As shown in Fig.6,7,8, 15 types of Hazmat Signs can be recognized.Hazmat Signs are recognized using darknet_ros. It can also recognize QR codes and heat sources, although there are no images.QR codes can be located on the map created by SLAM.

C. Communication

The operator and robot communicate wirelessly or by active tether. Details of the Wifi used are shown in Table V.

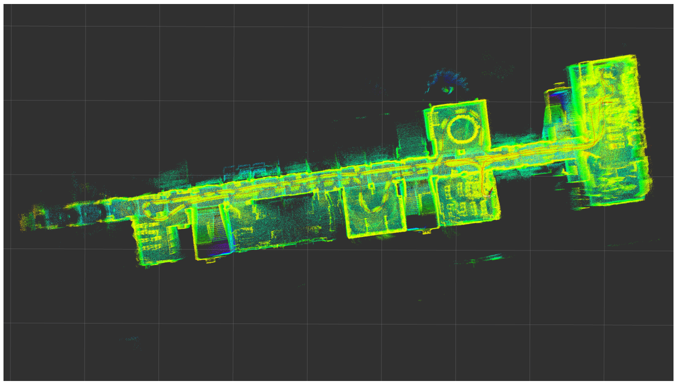

Fig. 5. 3D map by RTAB-Map

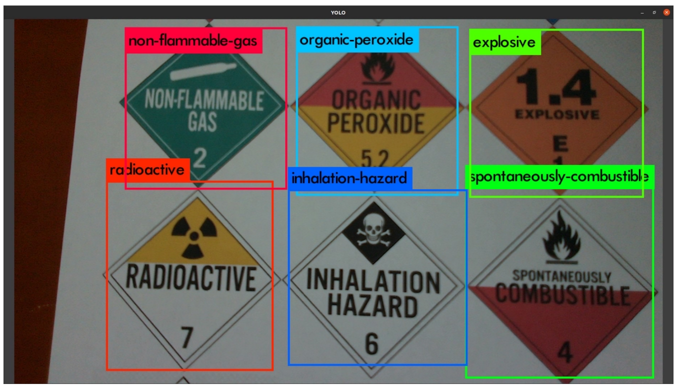

Fig. 6. Recognize Hazmat Signs part1

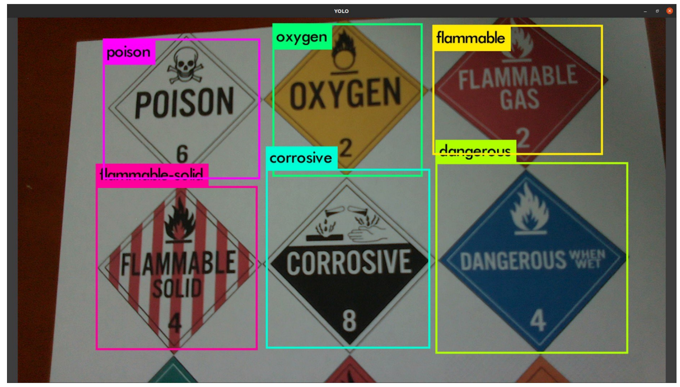

Fig. 7. Recognize Hazmat Signs part2

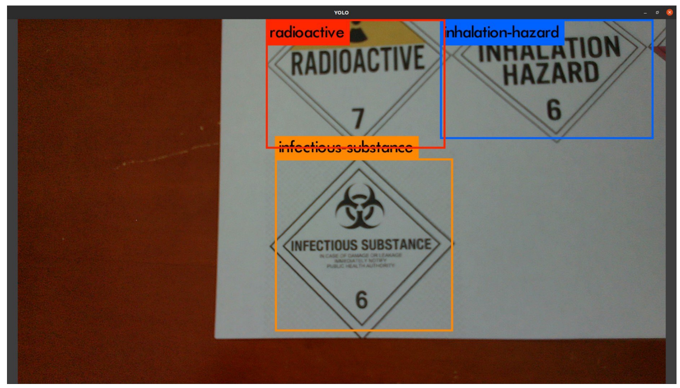

Fig. 8. Recognize Hazmat Signs part3

D. Human-Robot Interface

The interface has a notebook PC for information presentation and uses a dualsense2, a ps5 general-purpose controller, as an input device. The notebook PC displays information on the remote robot's state and surrounding environment obtained by the kamuy2's multiple sensors, and can simultaneously display multiple camera images, the robot's state and surrounding point clouds using the ROS standard interface Rviz.

III. Application

A. Set-up and Break-Down

The Kamuy2 robot has a separate robot arm, fuselage and sensors in a dedicated box. The arm and sensors are fixed to the fuselage frame with bolts and nuts. Installation takes about 30 minutes. The robot is then ready for operation once the battery is installed, the PC is started, the motors are initially positioned and the network is connected. Within an hour out of the box, the robot is ready to use. Even in the operator's seat, it takes about 15 minutes to start up the PC, connect the controller and connect the network.

B. Mission Strategy

The leg mechanism of the KAMUY2 offers the possibility to move quickly even in environments with steps. The leg mechanism also allows the torso to tilt freely, which means that the KAMUY2 has the potential to work with a high degree of freedom in confined spaces and in environments with obstacles. For these reasons, it should score highly in terms of mobility and dexterity. We would also like to map with large-scale mapping using two 3D-LiDAR units. However, due to the light weight of the body, the manipulators are not capable of lifting heavy objects. In addition, the vehicle is currently not equipped with autonomous driving capabilities.

C. Experiments

The kamuy2 hardware is currently in the final stages of development, while the software is still under development. For this reason, the current verification only confirms the operation with the initial programme. In the demonstration video, the walking of the leg mechanism and the movement of the manipulator can be seen. In the future, the software will be verified on a field simulating a staircase and in a RoboCup task.

D. Application in the Field

The leg robots we have developed are lightweight and easy to carry. Most modern rescue robots are crawler-type. In recent years, leg robots have been used in the industrial sector. Unlike crawler-type robots, leg robots are expected to be more adaptable to outdoor environments such as high steps, large slopes, sandy terrain and mud. The high degree of freedom of their bodies also allows them to work with manipulators adapted to such environments. Entering these environments, collecting

Fig. 9. Operator table

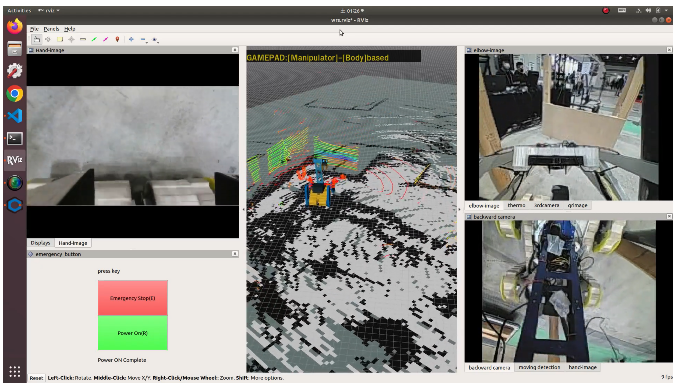

Fig. 10. Interface Example (Used in our robots in the past)

information and working with manipulators is expected to contribute to the further expansion of the rescue robot's range of activities.

IV. Conclusion

Team NITRo is developing a new quadruped robot, Kamuy2, for RoboCup 2023.Kamuy2 can move on its legs over uneven terrain and work with manipulators. It can also use two depth cameras and 3D-LiDAR to perform mapping. The legged robot is expected to be highly adaptable to uneven terrain due to its legs and can utilise its body's degrees of freedom to perform manipulator tasks on uneven terrain. At present, the hardware is almost complete, but the software is still under development. Further development is needed to realise an autonomously functioning robot in the future.

Appendix A
Qualification Video

Our development video is uploaded here.
State of Construction of Kamuy2
Teleoperation Interface

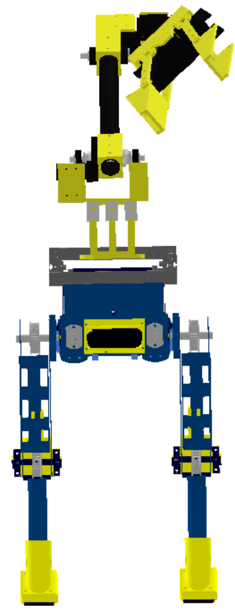

Fig. 11. CAD drawing of Kamuy2(View from front)

Appendix B
Team Members and Their Contributions

- Kotaro Kanazawa Mechanical design, Electoric, Programming
- Hayato Matsuo Manipulator
- Sota Sumikama SLAM algorithm, Network Communication
- Noritaka Sato Adviser

Appendix C
CAD Drawings

Appendix D
Lists

A. Systems List

For every system (each robot individually robot incl. support, Operator Station) answer the following items. One table per system. Remove entries that do not make sense. If a number is unknown try to estimate it or put a question mark (do not delete the entry if it might be interesting but you don't know the answer).

B. Hardware Components List

C. Software List

Acknowledgment

The authors would like to thank...

References

[1] A. Fukuda, K. Ushimaru, S. Sumikama, K. Kanazawa, and N. Sato, "Improvement of Robot Performance from World Robot Summit 2020 to RoboCup Asia Pacific 2021," in *The Twenty-Seventh International Symposium on Artificial Life and Robotics 2022 (AROB 27th 2022)*, Japan, 2022.

TABLE I
MANIPULATION SYSTEM

Attribute	Value
Name	Kamuy2
Locomotion	Legged
System Weight	15kg
Weight including transportation case	30kg
Transportation size	1.0 x 0.7 x 0.5 m
Typical operation size	0.6 x 0.4 x 0.7 m
Unpack and assembly time	60 min
Startup time (off to full operation)	15 min
Power consumption (idle/ typical/ max)	60 / 100 / 120 W
Battery endurance (idle/ normal/ heavy load)	60 / 30 / 20 min
Maximum speed (flat/ outdoor/ rubble pile)	- / - / - m/s
Payload (typical, maximum)	2/ 5 kg
Arm: maximum operation height	150 cm
Arm: payload at full extend	1kg
Support: set of bat. chargers total weight	2.5kg
Support: set of bat. chargers power	60W (100-240V AC)
Support: Charge time batteries (80%/ 100%)	90 / 120 min
Support: Additional set of batteries weight	2kg
Cost	7000 USD

TABLE II
OPERATOR STATION

Attribute	Value
Name	sousataku
System Weight	5kg
Weight including transportation case	6kg
Transportation size	0.4 x 0.6 x 0.3 m
Typical operation size	0.4 x 0.4 x 0.4 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
Any other interesting attribute	?
Cost	2000 USD

TABLE III
HARDWARE COMPONENTS LIST

Part	Brand & Model	Unit Price	Num.
DC Servo Motor	Dynamixel XM430-W350	USD 289.9	3
	Dynamixel XM430-W210	USD 289.9	1
	Dynamixel XH540-V270	USD 549.9	1
	Dynamixel XH540-V150	USD 549.9	2
	Dynamixel XW540-T140	USD 1,079.9	6
	Dynamixel XM540-W270	USD 419.9	8
DC/DC		?	1
Battery Management	Self-made	?	1
Battery Chargers		?	1
Batteries	You&me Li-Po Battery	?	1
Micro controller		?	1
Computing Unit	intel NUC11	?	1
	NVIDIA Xavier	?	1
Communication protocol	Dynamixel U2D2	?	1
WiFi Adapter		?	1
IMU	RT RT-USB-9axisIMU2	USD 161.32	1
Cameras	realsense d435i	USD 345	2
Cameras	BAFFALLO ?	USD 50	2
Infrared Camera	Initegra OWLIFT Type-F	USD 776.09	1
3D-LiDAR	Livox mid360	USD 672.7	2
Rugged Operator Laptop	Dell Precision mobile	USD 144439	1

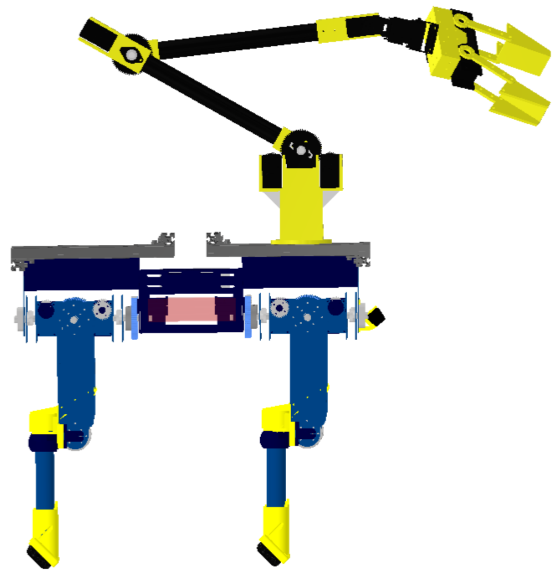

Fig. 12. CAD drawing of Kamuy2(View from right side)

TABLE IV
SOFTWARE LIST

Name	Version	License	Usage
Ubuntu	20.04	open	
ROS	Noetic	BSD	
Moveit!	Noetic	BSD	Manipulator controll
PCL [2]	1.8	BSD	Point cloud
OpenCV	2.4.8	BSD	LBP: QR detection
Hector SLAM [3]	Noetic	BSD	Mapping
Rtabmap	Noetic	GPL	Mapping
Zbar		BSD3	QR detection
darknet		BSD3	Object detection
dynamixl workbench		apache2.0	Motor control
Gait		closed	Leg control

[2] 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.
[3] S. Kohlbrecher, J. Meyer, O. von Stryk, and U. Klingauf, "A flexible and scalable slam system with full 3d motion estimation," in *Proc. IEEE International Symposium on Safety, Security and Rescue Robotics (SSRR)*. IEEE, November 2011.

TABLE V
WIFI HARDWARE DETAILS

Attribute	Operator Wifi	Robot Wifi
Vendor	TP-Link	NEC
Model	Archer GX90	Aterm WG2600HP3
Antenna Type	External	Built-in
Number of antennas	8	4
Maximum power	39.3W	18W
Power-Setting	unknown	unknown
Gain of antennas	unknown	unknown
Channels	36, 40, 44, 48, 52	
Mode	802.11a/n/ac/ax	
SSID	RRL_NITRo	