RoboCup Rescue 2016 Team Description Paper AutonOHM

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Info

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RoboCup Rescue 2016 TDP collection:
https://to-be-announced.org

***Abstract*—Team AutonOHM participates in RoboCup Rescue since 2012. The team focuses on autonomous behaviour and exploration for rescue robotics. Approaches like SLAM, navigation or exploration strategy are developed by the team. For this year the team wants to participate with a platform suitable for rough terrain and a manipulator. Through close contact with the local fire brigade of Nuremberg the team tries to create solutions that are applicable in the real world.**

***Index Terms*—RoboCup Rescue, Team Description Paper, Multi-Robot System, SLAM**

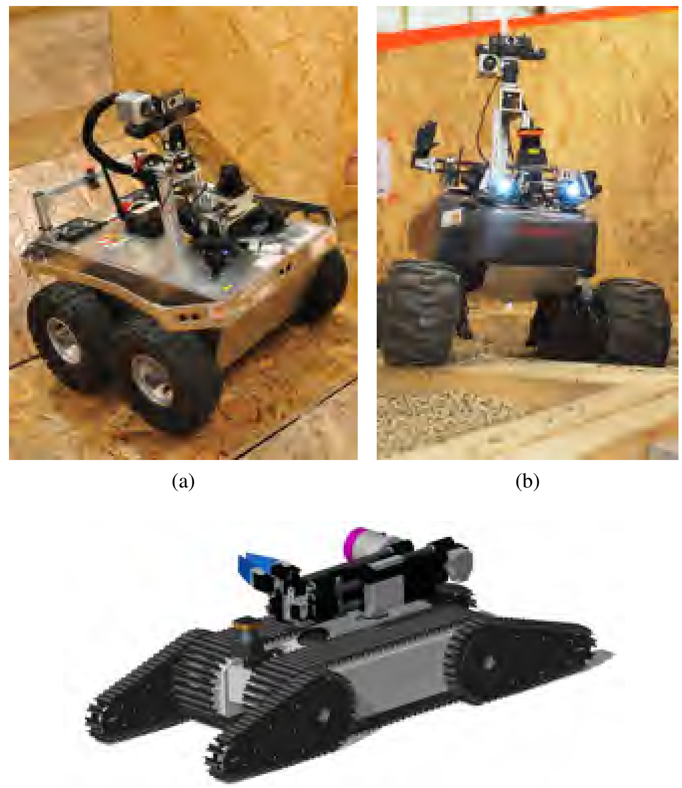

Fig. 1. Robot's of team AutonOHM: Georg (a) is used for autonomous driving and exploration. Robot Simon (b) can further be used for teleoperated driving. The new robot (c) will be capable of driving in rough terrain. Equipped with a manipulator it can inspect points of interest up to a height of 1.5 meters.

I. Introduction

AutonOHM participated in the RoboCup German Open [1] 2012 and 2013 with their teleoperated robot Georg. While team AutonOHM got second in 2013 for their second RoboCup Rescue competition they also qualified for the RoboCup World Championship in 2013, ending up in the 12th spot. Lessons learned in the first years, AutonOHM extended the team with a second robot called Simon for the RoboCup German Open 2014. Deploying this second, more maneuverable, robot for teleoperation and Georg for autonomous operation resulted in an overall second place. Furthermore, a second place in the Best of Class Autonomy Challenge was achieved in this year.

In 2015, AutonOHM participated with the same robots. The major focus was on increasing the level of autonomy, the quality of robot localization and environment mapping as well as cooperative SLAM (Simultaneous Localization and Mapping). These efforts enabled AutonOHM to win the RoboCup German Open 2015.

For 2016 the team brings up a new robot capable of driving in rough terrain and the red arena in the parcours accordingly (see Figure 1c).

Since 2014 team AutonOHM uses a self developed SLAM approach based on the TSDF (Truncated Signed Distance Function) [2]. In 2015, the approach was extended to multi-robot systems, allowing cooperative SLAM [3]. The team deployed the multi-SLAM successfully at the competition. Over the last years, the team gained expertise in different areas of robotics. This includes 2D and 3D mapping with LiDAR scanners, thermal imaging, sensor fusion and sensor development.

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II. System Description

All robots share the same software architecture which is based on the Robot Operating System (ROS). Furthermore, every robot uses the same sensors which makes it possible to deploy all algorithms on each robot.

A. Autonomous Robot: Georg

Georg, see Figure 1a, is used to explore unknown environment autonomously. According to the map, generated by the

SLAM algorithm (see Figure 3d), Georg is planning its path to inspect points of interest and to explore unknown environment time efficiently. Furthermore, it is equipped with algorithms for traversability analysis which considers the mobility capabilities of the robot chassis and therefore detects and maps dangerous or difficult obstacles. The traversability mapping uses 3D sensors, such as a structured light camera.

B. Teleoperated Robot: Simon

Some tasks are too complex to be handled autonomously. Challenging obstacles like ramps or rough terrain, for instance. The remote controlled robot Simon, see Figure 1b, has a higher mobility than Georg and is able to explore areas Georg cannot reach. Additionally, a manipulator arm is mounted on top, allowing the operator to inspect special points of interest such as small holes.

C. Rough Terrain Robot

The new robot (nameless till now), see Figure 1c, has been developed in cooperation with the RoboCup Rescue Robot Team of the Carinthia University of Applied Sciences Villach. With its chain wheel drive and four flippers it is able to handle complex obstacles like stairs and step-fields. A robot arm is able to do inspection and manipulation tasks like opening doors. The system will be remote controlled and mainly be used for rough terrain, such as the red arena. Currently, a new robot arm with seven degrees of freedom is under development. This will extend the skills of the robot to manipulation (e.g. opening doors) and enhance its inspection abilities.

D. Hardware

Georg and Simon are both wheeled. Due to higher motor power and higher ground clearance Simon is more capable to drive in rough terrain.

Both robots are equipped with a mini computer including a power-saving Intel Core i7.

1) Leveling Plattform: The levelling platform consists of two servo drives which are able to align the laser scanning plane horizontal with two degrees of freedom. The orientation of the chassis is measured with a inertial measurement unit (IMU), which is mounted on the chassis. An Arduino board receives the data from the IMU and calculates the required angles of the axes to keep the scanning plane aligned horizontally. Both servo drives are directly connected to the Arduino board. The levelling platform is an independent system on the robot.

2) Sensor Head: The sensor head is used to orientate different sensors with a single platform (see Figure 3c). Two servo drives ares used to pan and tilt the sensor head. It is equipped with a thermal imager camera, an RGB camera with autofocus and an RGB-D camera. All sensors are calibrated to each other by an extrinsic and intrinsic matrix. The sensor head is mainly used for visual inspection. Victims can be located quickly with its different visual sensors.

3) Motor Controller: Team AutonOHM developed an custom motor controller: The robot is equipped with 4 BLDC motors for the main drive and 4 BLDC motors for the flippers. The 8 controllers, based on Maxon EC amplifier DEC modules 50/5, are integrated in a compact motor driver stack and can be attached to an Arduino-compatible pin header, see Figure 3b. A ROS-module serves as main motor interface on a ARM-based UDOO quad board. The communication to the EC amplifiers is realized via the ATMEL co-processor.

4) Inspection Manipulator: Sometimes victims are not directly reachable for the mobile robots e.g. a victim is located behind an obstacle. For such cases, the mobile platform needs an inspection arm to improve victim localization abilities. The mobile robot Simon carries a two link robotic arm. Two servo drives allow the positioning of the tool center point (TCP) in a 2D plane. Additional two servo drives orientate the TCP. A video camera is attached to the TCP for visual inspection.

The rough terrain robot is equipped with a 7-axis robot arm (see Figure 3a). The TCP holds a time-of-flight camera and a gripper. Due to its 7 degrees of freedom the robot arm is able to fulfil complex inspection and manipulation tasks. The maximum payload is limited to 0.5 kg when it is fully extended. The robot arm can reach objects in a distance within 1.5 m. The control of the robot arm is done with MoveIt! based on ROS. To get a more stable inverse solver the kinematics plugin TRAC-IK by TRACLABS is used [4].

E. Software

The following section demonstrates the algorithms and software of AutonOHM for RoboCup Rescue League.

1) Low Level Control: An autonomous robot cannot switch tasks in reaction to a specific situation in its environment from scratch. Nevertheless, this is important for example if a robot is driving along a side walk and a person steps in front of it. In this situation the robot obviously needs to stop or avoid this person. If a robot is teleoperated, a human operator does this by default. An autonomous robot instead has to recognize, rate and change its behaviour.

Different states are linked by transitions. These transitions model the intelligence of the robot as they describe the adaptable behaviour of the robot. Task switching depends on the situation and is determined by the results of a state. In this case the robot is exploring the environment until a object of interest is detected. In the next step it is approaching and inspecting the object of interest. Either this can lead to a successful victim detection or not. Anyway the robots will conduct the exploration after the object of interest was evaluated. Figure 2 demonstrates the structure of the state machine.

2) Localization and Mapping: A own Simultaneous Localization and Mapping (SLAM) approach ohm_tsd_slam is used to generate a map of unknown environment with a 2D laser scanner (see Figure 3d). Information like the location of victims or points of interest are stored according to this map. A major feature of ohm_tsd_slam is that multiple robots

TABLE I
NETWORK COMMUNICATION FOR ROBOTS AND OPERATORS.

Frequency	Band	Power(mW)
2.4 GHz - 802.11g		< 125
4.0 GHz - 802.11a	157	< 125
400 MHz	1-8	< 500

can create a map together. Additionally, robust localization is guaranteed by use of a Random Sample and Consensus (RANSAC) approach [5].

3) Victim Detection: Vital signs are detected with help of different sensors. A sensor head is used to orientate the sensors without moving the whole robot. The sensor head uses video-, thermal- and RGB-D cameras for virtual perception. A CO2 sensor is mounted in front of the robot to detect breathing.

4) Navigation: Every Robot needs the capability to move from one point to an other. If the direct way is not free of obstacles, then a passable path must be found. Therefore path planning is needed. The path planning node from the autonomous robot uses a modified A*-Algorithm that uses cost-maps as heuristic hints [6].

5) Point of Interest Search: The wall finder searches walls in the Occupancy Grid Map. At first points which are a change over from free cells to occupied cells are extracted. In this set of points the wall finder searches for straight lines using RANSAC [5] algorithm. The Occupancy Grid Map is a 2D map, so straight lines are interpreted as walls. The wall finder locates both sides of an wall (see Figure 3f). Based on the found walls, target poses (points of interest) are computed and inspected by the robot.

6) Exploration: If the autonomous robot Georg has passed all points of interest (POI), it searches for unknown areas in the arena and moves towards these areas. This is also the main task in the RoboCup Rescue autonomy challenge. Therefore a ROS node defines target poses which are generated by a frontier exploration algorithm [7]. This algorithm uses the occupancy grid map to find regions which the autonomous robot has not seen before. The frontier algorithm searches for frontiers between free cells and unknown cells. These frontiers must fulfill some conditions, e.g. the frontier must be as wide as the robot.

F. Communication

For network communication the frequency of 5 GHz in channel 157 has been chosen. Another frequency of 440 MHz is used for 2-way radio communication between team members in the setup phase. Table I shows all used frequencies and their transmission power.

G. Human-Robot Interface

For moderate rough terrain (orange arena) the operator controls the robot with a game pad. The controlling is similar to computer games and allows easy adaptation. Furthermore the operator gets feedback with vibrations of the game pad in case of collisions. To prevent damage to the robot or to the environment a collision-avoidance system reduces the velocity while the robot nears up to an obstacle.

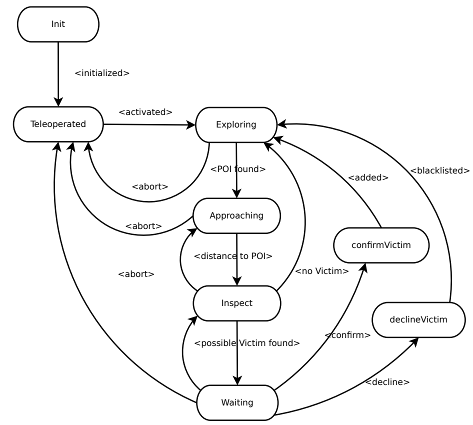


Fig. 2. State machine for autonomous behaviour.

The Graphical User Interface (GUI) consists of two parts. One part is the ROS display tool rviz and the second part a self written GUI with a custom Star Trek design. Figure 3e shows the GUI. On the left hand side, the driver camera is displayed. At the top right different optical sensors can be displayed.

To set up the robot for a mission, several measures have to be accomplished, for instance, powering up the drives and enable panning of the laser scanner. A checklist and basic training for team members and contributors minimize errors in start-up. For teleoperated driving the operator should be used to the operation with a game pad. Also, the small viewing angle of the camera takes time to get used to.

III. APPLICATION

A. Set-up and Break-Down

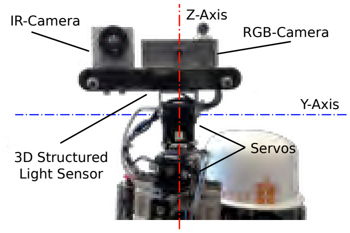
Due to pressure of time in competition, setup and handling of the robots and the operator station needs to be efficient. The network is powered by an uninterruptible power supply and can operate for several hours without external powering. Router, antenna and power supply are mounted to one unit for easy carrying. The operator uses a laptop computer to communicate over the network with the robot. Each robot is ready to run within few minutes. Because of the robots weight of more than 30 kilograms and the uninterruptible power supply, the set-up needs to be done by at least two persons.

B. Mission Strategy

Team AutonOHM focuses on multi-robot systems: One robot is not enough to fulfill the various tasks in RoboCup Rescue as well as in a real disaster scenario. Therefore several robots should help task forces to search for victims. For RoboCup Rescue one robot will be driven teleoperated while a second robot should perform autonomous exploration and victim detection. With this mission strategy points in competition could be ideally twice as high compared to a one robot system.

(a) Inspector Manipulator

(b) Motor Controller



(c) Sensor Head

(d) Map from SLAM

(e) GUI

(f) Wall Finding

(g) Collaboration with Firebrigade

Fig. 3. Different hardware and software components of our robot systems.

C. Experiments

Team AutonOHM testes different sensors for different scenarios: Optical sensors could fail in an environment containing smoke or dust. Beside optical sensors, ultra sonic range finder and RADAR sensors are tested to guarantee perception in such an environment. Since 2014 team AutonOHM collaborates with the local fire brigade of Nuremberg, testing sensors suitable for smoked areas and zero sight.

D. Application in the Field

In September 2013 the platform was employed in the training of the fire brigade of Dettelbach, Germany, in order to discover the requirements for human-robot collaboration (see Figure 3g . The acceptability of the fire-fighter depends on their age and their experience with computer technology. The robot should increase its durability and battery life more to perform well in a real disaster scenario. Also signal shielding from concrete dam or steel-girder constructions can cause errors and should be concerned.

IV. Conclusion

One single robot is not suitable to perform all tasks in RoboCup Rescue as well as in real disaster scenarios. In future work, the team will enhance the software used for both robots. Here, the focus especially is on the autonomy and the mapping capabilities. Traversability is an important point for autonomy. The autonomous robot has to decide if it is able to drive through the new explored terrain. A 3D sensor is essential for this task, a possible approach is to map the height of the terrain and search for steep gradients in this map. Additionally, obstacle classification will be integrated in the software of all robots, to check traversability and enhance the exploration capabilities. Furthermore, there are additional points to score with obstacle classification. The last point is the enhancement of the self developed multi-robot SLAM. An other important part is the development of an intuitive robot arm control. Such a contol system must contain semi-autonomous control mechanisms for inspection and grasping.

Appendix A
Team members and Their Contributions

The team AutonOHM consists out of serveral students and research assistants of the Nuremberg Institute of Technology. The following list is in alphabetic order:

- Daniel Ammon SLAM
- Jörg Arndt Algorithms
- Martin Fees Mechanical design
- Tobias Fink SLAM
- Franziska Frenzel GUI
- Johanna Gleichauf Lokalisierung
- Philipp Koch Traversability
- Markus Kühn SLAM
- Stefan May SLAM
- Christian Merkl Exploration
- Christian Pfitzner Autonomy
- Michael Schmidpeter Navigation
- Johannes Vollet Sensor Processing

Appendix B
Lists

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TABLE V
OPERATOR STATION

Attribute	Value
Name	Operator Station
System Weight	3.2kg
Weight including transportation case	4.5kg
Transportation size	0.4 x 0.4 x 0.2 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)	5 / 3 / 2 h
Cost	EUR 2,800

TABLE VI
HARDWARE COMPONENTS LIST

Part	Brand & Model	Unit Price	Num.
Drive motors	Maxon EC 30 200 W	EUR 830	4
	Maxon RE 50 200 W	EUR 870	2
	Maxon EC max 40 70 W	EUR 490	4
	Robotis Dynamixel AX-12	EUR 45	4
	Robotis Dynamixel MX-28	EUR 180	6
	Robotis Dynamixel MX-64	EUR 280	2
	Robotis Dynamixel MX-106	EUR 460	2
Motor drivers	DEC 50/5	EUR 50	10
	Robotis OpenCM9.04 Board	EUR 15	2
	USB2Dynamixel	EUR 45	2
Gear	Maxon GP 42 C	EUR	4
DC/DC	M4 ATX	EUR 85	4
Batteries	12V 10 Ah lead-acid battery	EUR 35	4
	8x3.3V LiFePO4	EUR 400	1
Micro controller	Arduino Nano	EUR 5	6
Computing Unit	Mini-PC	EUR 800	3
WiFi Adapter	Netgear N900	EUR 30	3
IMU	XSense Mti-10	EUR 1,100	1
Cameras	Logitech c920	EUR 65	4
	Logitech c930	EUR 70	2
	Genius F100	EUR 35	2
	Sony PS Eye Camera	EUR 5	2
	Asus Xtion Pro	EUR 135	3
Infrared Camera	Optris PI160	EUR 2,500	3
LRF	Sick TiM561/551	EUR 1,250	3
CO_2 Sensor	MG811	EUR 30	3
Robot Arm	Harmonic Drive(HD) CHA-17A-100-E	EUR 2,400	1
	HD FHA-14C-100-E	EUR 1,600	2
	HD FHA-11C-100-E	EUR 1,500	1
	Robotis Dynamixel MX-28	EUR 180	5
Motor drivers	Elmo MC Gold DC Whistle	EUR 570	4
	Robotis OpenCM9.04 Board	EUR 15	1
Power Station	USV APC Smart UPS 750	EUR 250	1
Rugged Operator Laptop	Dell M4800 Workstation	EUR 3,500	1

TABLE II
ROBOT GEORG

Attribute	Value
Name	Georg
Locomotion	wheeled
System Weight	30kg
Weight including transportation case	36kg
Transportation size	0.6 x 0.6 x 0.5 m
Typical operation size	0.5 x 0.8 x 0.4 m
Unpack and assembly time	10 min
Startup time (off to full operation)	5 min
Power consumption (idle/ typical/ max)	60 / 200 / 600 W
Battery endurance (idle/ normal/ heavy load)	240 / 120 / 60 min
Maximum speed (flat/ outdoor/ rubble pile)	1.5 / 1 / - m/s
Payload (typical, maximum)	3/ 10 kg
Support: set of bat. chargers total weight	2.5kg
Support: set of bat. chargers power	1,200W (100-240V AC)
Support: Charge time batteries (80%/ 100%)	90 / 120 min
Support: Additional set of batteries weight	8kg
Cost	EUR 18,000

TABLE III
ROBOT SIMON

Attribute	Value
Name	Simon
Locomotion	wheeled
System Weight	50kg
Weight including transportation case	55kg
Transportation size	0.7 x 0.6 x 0.7 m
Typical operation size	0.7 x 0.6 x 0.7 m
Unpack and assembly time	3 min
Startup time (off to full operation)	5 min
Power consumption (idle/ typical/ max)	100 / 350 / 1200 W
Battery endurance (idle/ normal/ heavy load)	600 / 240 / - min
Maximum speed (flat/ outdoor/ rubble pile)	3 / 3 / - m/s
Payload (typical, maximum)	10/ 65 kg
Arm: maximum operation height	80 cm
Arm: payload at full extend	0.25 kg
Support: set of bat. chargers total weight	2.5kg
Support: set of bat. chargers power	1,200W (230V AC)
Support: Charge time batteries (80%/ 100%)	120 / 200 min
Cost	EUR 23,000
Based on	Summit XL

TABLE IV
ROBOT NEW ONE

Attribute	Value
Name	NewRobot
Locomotion	tracked
System Weight	70kg
Weight including transportation case	85 kg
Transportation size	0.8 x 0.5 x 0.5 m
Typical operation size	1.2 x 0.5 x 0.5 m
Unpack and assembly time	15 min
Startup time (off to full operation)	10 min
Maximum speed (flat/ outdoor/ rubble pile)	1 / 1 / - m/s
Arm: maximum operation height	155 cm
Arm: payload at full extend	0.5kg
Cost	EUR 26,000

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TABLE VII
SOFTWARE LIST

Name	Version	License	Usage
Ubuntu	14.04	open	Operation System
ROS [8]	indigo	BSD	Middle Ware
PCL [9]	1.7	BSD	ICP
OpenCV [10], [11]	2.4.8	BSD	Victim detection
OpenCV [12]	2.4.8	BSD	LBP: Hazmat detection
Qt4	4.8	GPL	GUI
ohm_tsd_Slam [2], [3]	indigo		Multi-Robot Slam
optris_drivers	indigo	BSD	Thermal Imager
MoveIt! [13]	indigo	BSD	Robot arm control
TRAC-IK [4]	v1.4.0	BSD	Inverse kinematic

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