RoboCup Rescue 2018 Team Description Paper AutonOHM

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Info

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

***Abstract*—Team AutonOHM has been participating in the RoboCup Rescue League since 2012. The team focuses on autonomous behavior and exploration for rescue robotics. Our strength lies within implementations like SLAM, navigation, or exploration strategies. Approaches for autonomous grasping and automated object detection are under development. Through close contact with the local fire brigade of Nuremberg, the team tries to create solutions that are applicable to disaster scenarios.**

***Index Terms*—RoboCup Rescue, Team Description Paper, Autonomous Explorations, SLAM, Manipulation System**

I. Introduction

AUTONOHM participated in the RoboCup German Open [1] in 2012 and 2013 with their teleoperated robot Georg. While team AutonOHM achieved the second place in 2013, they qualified for the RoboCup World Championship in Eindhoven in 2013, ending up in the 12th spot. In 2014 the AutonOHM team was extended by a second robot called Simon. Deploying this second, more maneuverable robot for teleoperation and Georg for autonomous operation, resulted in an overall second place at the RoboCup GermanOpen in 2014. Furthermore, a second place in the Best in 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 in 2015. In 2016 the team joined the RoboCup world championship in Leipzig with a new robot platform (see Figure 1) capable of driving in rough terrain scenarios [2]. A new redundant 7-DOF manipulator with three links was constructed and first tests were executed. Further developments were made until participating in the German Open in Magdeburg in 2017. Team AutonOHM achieved the highest score for the most repetitions for the challenges 'step field' and 'maneuvering center' autonomously. Additionally, they reached the second place within the Best in Class Autonomy challenge. For 2018 the team intends to show improved skills including grasping with a manipulator as well as tackling more challenges autonomously. Since 2014 team AutonOHM uses a self-developed SLAM approach based on the TSDF (Truncated Signed Distance Function) [3], [4], [5]. 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, sensor development as well as robot arm manipulation.

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Fig. 1. Robot Schroedi equipped with a 7-DOF manipulator for inspecting points of interest up to a height of 1.5 meters and grasping objects. This robot is capable of driving in rough terrains.

A. Improvements over Previous Contributions

Since the GermanOpen competition in 2017 the following improvements and developments have taken place: During the finals in Magdeburg, the drivetrain was seriously damaged due to material fatigue and attrition. A new concept was developed where the power transmission was changed from feather keys to clamp connections. Furthermore, a new iteration of motor controllers as well as flipper controllers was implemented. A new smooth inverse kinematics solver which combines an iterative and an analytical solution is now in use for manipulation tasks. Another focus is the extension of the existing object detection. Research in the field of person detection for disaster scenarios as well as autonomous shunting [6], showed that the combination of heterogeneous sensors leads to more robustness. This gained know-how lead to further developments in the victim detection of Schroedi. For example, an automated detection process is implemented using thermal and RGB-camera images. This concept will be applied to point cloud and RGB-D data.

II. System Description

The software architecture of our robot is based on the Robot Operating System (ROS) [7]. The chassis of Schroedi has been developed in cooperation with the RoboCup Rescue Robot Team of the Carinthia University of Applied Sciences Villach [8]. With its chain wheel drive and four flippers, it is able to handle complex obstacles like stairs and step-fields. The robot arm is capable of inspection and manipulation tasks like opening doors. The system will be remote controlled and additionally in most of the maneuvering challenges autonomously as well.

A. Hardware

The robot's hardware is designed for robust longterm missions in disaster areas and will be described in this section.

a) Leveling Plattform: The leveling platform consists of two servo drives which are able to align the laser scanning plane horizontal with two degrees of freedom (Figure 2d). The orientation of the chassis is measured with an 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 leveling platform is an independent system on the robot.

b) Sensor Head: The sensor head is used to orientate different sensors with a single platform (Figure 2a). Two servo drives are used to pan and tilt the sensor head. It is equipped with an infrared 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 using different visual sensors. Figure 2a illustrates the sensor head with its sensors.

c) Motor Controller: Team AutonOHM developed a custom motor controller: The robot is equipped with four BLDC motors for the main drive and four BLDC motors for the flippers (see Figure 2b). The eight controllers, based on Maxon EC amplifier DEC modules 50/5, are integrated into a compact motor driver stack. The stack consists of four NXP KV31 based slave boards, each of which controls two motors. The Atmel Atmega328 based master board, which also includes the required power supplies and galvanic isolation, connects the stack via USB to the ROS-System.

d) Manipulator: Sometimes victims are not directly reachable for the mobile robot, e.g. a victim is located behind an obstacle. For such cases, the mobile platform needs an inspection arm to improve victim localization abilities. Schroedi is equipped with a redundant 7-DOF robot arm. To achieve higher compactness of the manipulator by constant operation range it has three links instead of two links compared to most existing robot arm configurations. (see Figure 2c). The TCP holds an RGB-D camera, audio sensors, a CO2 sensor and a gripper (see Figure 2e). Due to its 7 degrees of freedom the robot arm is able to fulfill 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 within a distance of 1.5 m. The manipulator can be controlled teleoperated with a gamepad controller or autonomously.

e) Drivetrain: After a mechanical breakdown during the RoboCup German Open Finals in 2017, the mechanical parts of the drivetrain had to be improved. The shaft-hub connections were optimized from a form-fit connection with a feather key to a force-fit connection using a clamping set. The advantage of the new concept (see Figure 2f) is higher stability even if alternating and bunting loads occur. The drivetrain is designed to overcome slopes of 45° as well as 15° slopes with an additional load of 50 kg.

B. Software

The following section demonstrates the algorithms and software of AutonOHM for the RoboCup Rescue League. All software is executed on a power-saving Intel Core i7 mini computer.

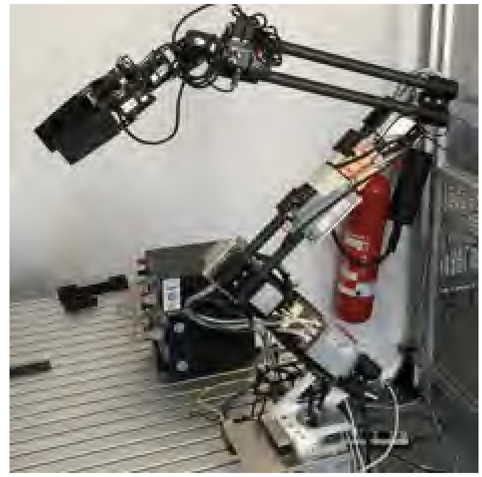
a) Low Level Control: The low-level control of Schroedi is responsible for the basic control of actors and the access to the sensor signals. The commonly known robot middleware Robot Operating System (ROS) is responsible for the communication [7]. The software is structured in nodes, each containing a single executable. The exchange of information between these ROS nodes is realized by ROS datatypes, e.g., messages, services or actions, via TCP/IP. On the startup of the robot, different checks are applied to the sensors and actors. If tests fail – e.g., a sensor cannot provide data in sufficient cycle time, or an actor does not provide feedback, the startup aborts and the operator of the robot is informed.

b) Localization and Mapping: An own Simultaneous Localization and Mapping (SLAM) approach ohm_tsd_slam is used to generate a map of unknown environment with a 2D laser scanner. Information like the location of victims or points of interest is stored according to this map. A major feature of ohm_tsd_slam is that multiple robots can create a map together. Additionally, robust localization is guaranteed by the use of a Random Sample and Consensus (RANSAC) approach [9].

c) Victim Detection: Vital signs are detected with the help of different sensors. A sensor head is used to orientate the sensors without moving the whole robot. The sensor head uses

(a) Sensor head with IR-Camera, RGB-Wide-Angle-Camera, 3D Structured-Light-Sensor.

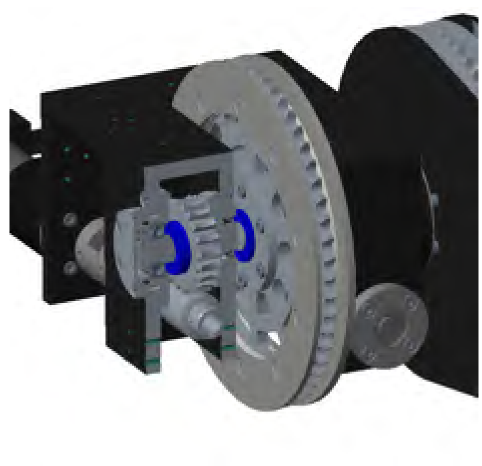
(b) Motorcontroller set up for the main drives and flippers.



(c) 7-DOF manipulator for inspecting points of interest up to a height of 1.5 meters and grasping objects.

(d) Leveling platform

(e) End-effector with its sensors.



(f) Drivetrain in detail.

Fig. 2. Mechanical components and sensor concepts of Schroedi.

video-, thermal- and RGB-D cameras for virtual perception. A CO2 sensor is mounted in front of the robot to detect breathing. An approach for the automatic detection of heated objects was developed to allow a faster sensor check as well as to improve the object detection during exploration missions [10]. Parts of the developed software are free to use and open access via [11].

d) Navigation: For autonomous navigation, the ROS package RONA (Source: https://github.com/schmiddey/rona) is used. It contains path planning based on the A* algorithm and is suitable for single and multi-robot path planning [12]. Additionally, the package contains basic implementations for path control. Also, it includes an implementation for frontier-based exploration. In contrast to the common ROS navigation stack, RONA is lightweight and needs less parametrization.

e) Point of Interest Search: For a real disaster scenario, the generated map is searched for wall segments. At first, points which change their state from free cells to occupied cells are extracted. In this set of points the wall finder searches for straight lines using RANSAC [9] algorithm. The Occupancy Grid Map is a 2D map, so straight lines are interpreted as walls. The wall finder locates both sides of a wall. Based on the extracted walls, target poses (points of interest) are computed and inspected by the robot. This improves the robustness of finding potential victims.

f) Exploration: Schroedi can explore unknown environments based on laser scan sensor data. The sensor data is processed by the Frontier Exploration approach, presented by Yamauchi [13]. 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. Additionally, the frontiers are sorted and prioritized based on their size and the navigation distance to the robot. Although the exploration does not rely on user interaction, a user can define areas in the map, which are prioritized higher, to enhance the performance in exploration.

g) Arm control: The complexity to solve the inverse kinematic problem rises with the number of joints, and with their configuration. The manipulator of Schroedi – shown in Figure 2c – has seven joints. Joints $2-4$ are parallel

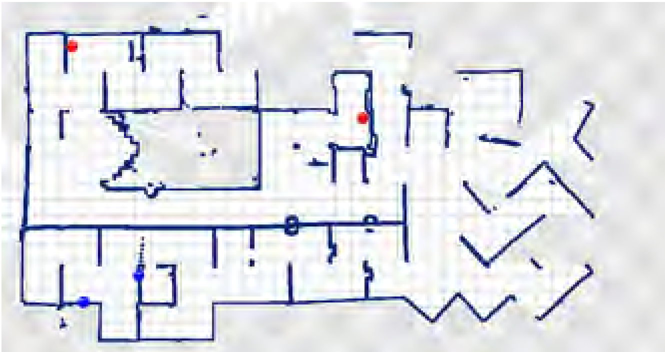


Fig. 3. Map generated by the ohm_tsd_slam

(a) Extracted pipestar represented in a PointCloud. Pipe detection is realised with PCL [15] [9].

(b) Found pipes are marked with green lines in RGB image. Realised with [16].

Fig. 4. Perception for autonomous manipulation.

which results in redundancy and joints $5-7$ build a spherical wrist. To solve the inverse kinematics problem there is a combined analytical and iterative solution implemented. The orientation problem of the end-effector is solved analytically due to the spherical wrist. The positioning problem of joints $1-4$ is solved with an optimization algorithm based on [14]. The solution is stable near singularities and considers joint limits. The end-effector is controlled manually with a gamepad controller. To solve tasks autonomously the arm uses the input data of two 3D-cameras (see Figure 4a and 4b).

C. 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.

TABLE I
NETWORK COMMUNICATION FOR ROBOTS AND OPERATORS.

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

D. Human-Robot Interface

For mobility and maneuvering challenges the robot is controlled by a gamepad. The controlling is similar to computer games and allows easy adaptation. Furthermore, the operator gets feedback with vibrations of the gamepad in case of collisions. To prevent damage the robot or to the environment, a collision-avoidance system reduces the velocity while the robot nears up to an obstacle.

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 during the start-up phase. For teleoperated driving, the operator should be used to the operation with a gamepad. 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. The robot is ready to run within a few minutes. Because of the robot's weight of more than 70 kilograms and the uninterruptible power supply, the set-up needs to be done by at least two persons.

B. Mission Strategy

In the classic rescue competition, 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. Since the competition changed in 2016, the team focues more on one robot, capable of driving in different terrains, combined with the ability to do several tasks autonomously. In the setup phase, the team tries to score as many multipliers as possible. This is possible due to the different sensors mounted on Schroedi and also due to its manipulator. After the regular time driving teleoperated, in some challenges, the robot is able to continue autonomously. Such challenges are the challenges for manouvering (MAN1, MAN2, MAN4, MOB1), as well as all five autonomous challenges, including mapping and exploration with positive and negative obstacles.

C. Experiments

Team AutonOHM tested different sensors for different scenarios: Optical sensors could fail in an environment containing smoke or dust. Besides optical sensors, ultra sonic range

Fig. 5. Robot Schroedi and the fire brigade of Nuremberg.

finders and RADAR sensors are tested to guarantee perception in such an environment. This is why the fusion of different sensors is necessary to provide enough robustness [6]. During a research project with the Deutsche Bahn (German Railway), where a shunting locomotive was automated, experiences were made [10]. Since 2014 team AutonOHM collaborates with the local fire brigade of Nuremberg, testing sensors suitable for zero sight areas due to smoke.

D. Application in the Field

Since 2013 team AutonOHM has been cooperating with the fire brigade of Dettelbach, Germany as well as in Nuremberg, Germany in order to discover the requirements for human-robot collaboration. (see Figure 5) 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 a concrete dam or steel-girder constructions can cause errors and should be concerned. In August 2016 a workshop took place in cooperation with the fire brigade No. 3 in Nuremberg. Different techniques using different cameras and laser scan mapping were demonstrated. The laser scan maps allow the incident commander to direct his men for finding victims in time. This will save lives in the future [17].

IV. Conclusion

The mobile robot Schroedi is starting in his third competition year. The focus of the team within the last two years was to optimize the drivetrain after some mechanical breakdowns. A new set of motor and flipper controllers was implemented and the drive train got a complete revision with a changed force transmission. Due to the changed hardware, the team's focus in 2018 will be on autonomy and mapping capabilities. One important aspect will be autonomous traversability. The autonomous robot must decide if it is able to drive through the new unexplored 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 into the software, to check traversability and enhance the exploration capabilities. Another crucial part is the development of an autonomous robot arm control. With the experiences gained in autonomous mapping and navigation, the next goal for the team is to solve some of the dexterity challenges autonomously.

TABLE II
SCHROEDI

Attribute	Value
Name	Schroedi
Locomotion	tracked
System Weight	70kg
Weight including transportation case	85kg
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
Power consumption (idle/ typical/ max)	60 / 200 / 800 W
Battery endurance (idle/ normal/ heavy load)	240 / 120 / 60 min
Maximum speed (flat/ outdoor/ rubble pile)	1 / 1 / - m/s
Payload (typical, maximum)	3/ 10 kg
Arm: maximum operation height	155 cm
Arm: payload at full extend	0.5kg
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	2kg
Cost	EUR 26,000

Appendix A
Team members and Their Contributions

Team AutonOHM consists of serveral students and research assistants of the TH Nuremberg Georg Simon Ohm. The following list is in alphabetic order:

- Johanna Gleichauf — Object detection
- Philipp Koch — Traversibility
- Stefan May — SLAM
- Christian Pfitzner — Perception
- Lukas Pichl — Mechanical Design
- Johannes Vollet — Electronical Design
- Johannes Ziegler — Manipulation

Appendix B
Lists

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TABLE III
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 IV
HARDWARE COMPONENTS LIST

Part	Brand & Model	Unit Price	Num.
Drive motors	Maxon EC 30 200 W	EUR 830	4
	Maxon EC max 40 70 W	EUR 490	4
	Robotis Dynamixel MX-28T	EUR 175	4
Motor drivers	Maxon DEC 50/5	EUR 57	8
	USB2Dyanmixel	EUR 45	1
Gear	Maxon GP 42 C	EUR	4
DC/DC	Internal Development	EUR 35	2
	M3-ATX-HV 6-34V DC/DC (95 W)	EUR 57	2
Batteries	mylipo HV - Lipo 4600mAh 22,2V 6S 30C/60C	EUR 60	4
Micro controller	Arduino Micro	EUR 18	1
SBC	AAEON UP-Board 4GB-Ram 64GB-EMMC	EUR 140	2
Computing Unit	Mini-ITX PC, msi H110I PRO	EUR 700	1
Access Point	Edimax Gemini RE11S	EUR 60	1
WiFi Adapter	Asus RT-AC66U	EUR 100	1
IMU	XSense Mti-10	EUR 1,100	1
	Bosch BNO055	EUR 30	1
Cameras	Asus Xtion Pro Live	EUR 135	1
	Intel Realsense R200	EUR 160	1
	IDS U3-3241LE	EUR 400	1
Infrared Camera	Seek Thermal Compact-Pro	EUR 500	1
	FLIR Lepton	EUR 200	1
LRF	SICK TIM-571	EUR 2500	1
Microphone	Rode VideoMicro	EUR 40	1
CO_2 Sensor	DFRobot SEN0220	EUR 70	1
7-axis Robot Arm	Harmonic Drive(HD) CHA-17A-100-E	EUR 2,400	1
	HD FHA-14C-100E	EUR 1,600	2
	HD FHA-11C-100E	EUR 1,500	1
	Robotis Dynamixel MX-28	EUR 175	5
Motor drivers	Elmo MC Gold DC Whistle	EUR 600	4
	Robotis OpenCM9.04 Board	EUR 15	1
Power Station	OpenUPS, Multistar High Capacity 4S 10000mAh	EUR 115	1
Rugged Operator Laptop	Dell M4800 Workstation	EUR 3,500	1

TABLE V
SOFTWARE LIST

Name	Version	License	Usage
Ubuntu	16.04	open	Operation System
ROS [7]	kinetic	BSD	Middle Ware
PCL [15]	1.7	BSD	ICP
OpenCV [18], [19]	2.4.8	BSD	Haar: Victim detection
OpenCV [16]	2.4.8	BSD	LBP: Hazmat detection
Qt4	4.8	GPL	GUI
ohm_tsd_slam	kinetic		Multi-Robot SLAM
optris_drivers	kinetic	BSD	Thermal Imager
MoveIt!	kinetic	BSD	Robot arm control
TRAC-IK	v1.4.0	BSD	Inverse kinematic

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