RoboCupRescue 2013 - Robot League Team
RRT-Team FH Wels (Austria)

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Abstract. This paper describes the work of the RRT-Team (*RoboRacingTeam) FH-Wels* developing and building mobile rescue robots and UAVs. The team consists of research associates and students at the *University of Applied Sciences Upper Austria*.

This paper includes the preliminary results which are achieved so far about map building, localization and autonomous victim identification. Furthermore the implementation of SLAM and victim detection and a novel mechanism with a dynamic drive system for locomotion is described. Additionally the construction of a modular robotic arm is introduced.

1. Introduction

The RRT-Team FH-Wels [1] includes members which already have achieved experience by building autonomous robots for competitions and has been established in late 2007. These robots were able to win competitions such as the Robot-Challenge in Vienna (AUT) the Robot SM in Gothenburg (SWE) and the RoboGames in San Francisco (USA). The robots also started at the Eurobot in La Ferté Bernard (FRA), Rapperswill(CH) and Heidelberg (GER) and the team won the Eurobot 2011 in Astrakhan (Rus).

The team participated for the first time in RoboCup Rescue 2009. The RoboCup Rescue League is a competition where autonomous robots navigate through an arena with different level of difficulty such as uneven underground, obstacles and stairs. According to those requirements the development of the robots is very complex and combines multiple disciplines such as mechanical engineering, electrical engineering and programming. The RoboCup Rescue League requires the highest demands on the motor and sensory abilities of the robots. The robot is developed specially for the use in the field of security and emergency application. The preliminary aim is to build autonomous and teleoperated robots which are able to drive through an unstructured environment and search for victims. This includes generating a map of the environment and characterizing and locating victims as well as recognizing dangerous situation caused by fire and gas. Building a robot which is supposed to attend the RoboCup Rescue League requires high degree of versatility and experience which makes it difficult to start in this competition from scratch.

The mechanical systems of the robot including the robotic arm are assembled so far. Also the single modules such as the controller board and the peripheral system such as cameras and sensors are tested successfully. The main focus concerns the exploration of all different arenas of the competition by generating a two-dimensional map and the detection of victims. The autonomous navigation on rough terrain is a challenging problem for mobile robots because it requires the ability to analyze the environment and make decision which parts can be traversed or need to be bypassed. Due to the developed design, the robots are very fast and agile so it is able to handle all of the arenas. We want to start with two robots, one with teleoperation mode and the other robot to navigate autonomously in the yellow arena and if it is a good run, also navigate autonomously in the orange arena.

2. Team Members and Their Contributions

• Raimund Edlinger	Team Leader, Mechanical design, SLAM, Vision
• Michael Zauner	Electronic and Control
• Christina Mergl	Mechanic and Team Administration
• Armin Hopf	ROS-Software integration, GUI, 2D-Mapping
• Christoph Pauzenberger	Mechanic and Simulation of the robot arm
• David Stiebinger	Victim Detection/CO2-Sensor
• Roland Giuliano	2D-Mapping and Path Planning
• Stefan Bichler	Programming robot arm
• Karina Nöhammer	Victim and Hazmat Label Detection
• Matthias Kofler	Vision, Victim Detection
• Walter Rokitansky	Advisor

3. Operator Station Set-up and Break-Down (10 minutes)

The rescue robots are remote controlled by a laptop via a *Microsoft Xbox 360 controller*. This so-called operator station is transported in a notebook case. Our system consists of one or more UGV`s which can be used autonomously or remote controlled.

Figure 1: Xbox 360 Wireless Controller

For transporting the robot itself it can be packed into a moveable case with wheels. All sensitive and expensive sensors such as thermo camera or laser range finder are packed separately in a case. The whole setup and breakdown procedure can be accomplished within less than 10 minutes. The procedure includes starting up the operation station, controlling the network status, checking if the sensor are working properly and to make sure that all actuators in the initial position.

4. Communications

For the communication between robot and operator station a *Linksys E1000* router is used which is operating on the 2.4 GHz and 5 GHz band. The wireless communication is used for both, the autonomous modus as well as for the remote control modus.

Rescue Robot League			
RRT-Team FH Wels(AUSTRIA)			
MODIFY TABLE TO NOTE ALL FREQENCIES THAT APPLY TO YOUR TEAM			
Frequency	**Channel/Band**	**Power**	**Bandwith**
2.4 GHz - 802.11a/n	channel 1-15	32mW	54-300 Mbit/s
5 GHz - 802.11a/n	channel 30-50	32mW	54-300 Mbit/s
2.4 GHz - 802.15.4	channel 1-10	50mW	115 kBit/s

Table 1. Wireless LAN Communication

5. Control Method and Human-Robot Interface

5.1. Teleoperation

During the remote controlled modus the motion of the robot is controlled by a *Microsoft Xbox 360 controller,* which is connected to the operator station. Several cameras are mounted on the robot, one at the front and the other one at the rear side of the robot which gives images of the environment. Furthermore a thermo camera and standard cameras are mounted on the top of a robotic arm and provide live stream for the operator.

5.2. ROS Fuerte Turtle

ROS - Robot Operating System is an open-source, meta-operating system for robots. It provides the services, which are expected from an operating system, including hardware abstraction, low-level device control, implementation of commonly-used functionality, tools for visualization, message-passing between processes and package management [18].

The RRT-Team uses the release ROS Fuerte. A basic ROS installation for RoboCup Rescue was developed at the workshop on Standard Robotic Software Architecture for RoboCup Rescue based on ROS in Koblenz, Germany (2011), ROS Robocup Rescue Summerschool in Graz, Austria (2012) and SSRR Summer School in Alanya, Turkey (2012) [12].

5.3. Graphical User Interface

The tool *rqt* is a software framework that implements the various GUI tools in the form of plugins. One can run all the existing GUI tools as dockable windows within *rqt*. The tools can still run in a traditional standalone method, but *rqt* makes it easier to manage all the various windows on the screen at one moment.

The graphical user interface (ROSGUI) is about to be developed which is supposed to display current information of the terrain and environment. This includes the pictures of the thermo camera and the RGB-cameras as well as the data of the CO_2 sensor, laser range finder and several other sensors. Additionally the operator gets important information about the robot's battery status and warnings for the obstacle avoidance.

6. Map generation/printing

6.1. 2D-Mapping

One of the most important tasks at the RoboCupRescue is to explore an unknown terrain and create a map of this terrain. This leads to the common known SLAM (Simultaneous Localization and Mapping) problem. As described in [2] the Robot has to build a map while it is localizing itself. To solve the SLAM problem hector_slam is used by the RRT-Team. Hector_slam consists of several ROS (Robot Operating System) packages. One node of these packages is the hector_mapping node.

Hector_mapping is a SLAM approach that can be used without odometry as well as on platforms that exhibit roll/pitch motion (of the sensor, the platform or both). It leverages the high update rate of modern LIDAR systems like the Hokuyo UTM-30LX and provides 2D pose estimates at scan rate of the sensors (40Hz for the UTM-30LX). While the system does not provide explicit loop closing ability, it is sufficiently accurate for many real world scenarios. The system has successfully been used on Unmanned Ground Robots, Unmanned Surface Vehicles, Handheld Mapping Devices and logged data from quadrotor UAVs [3].

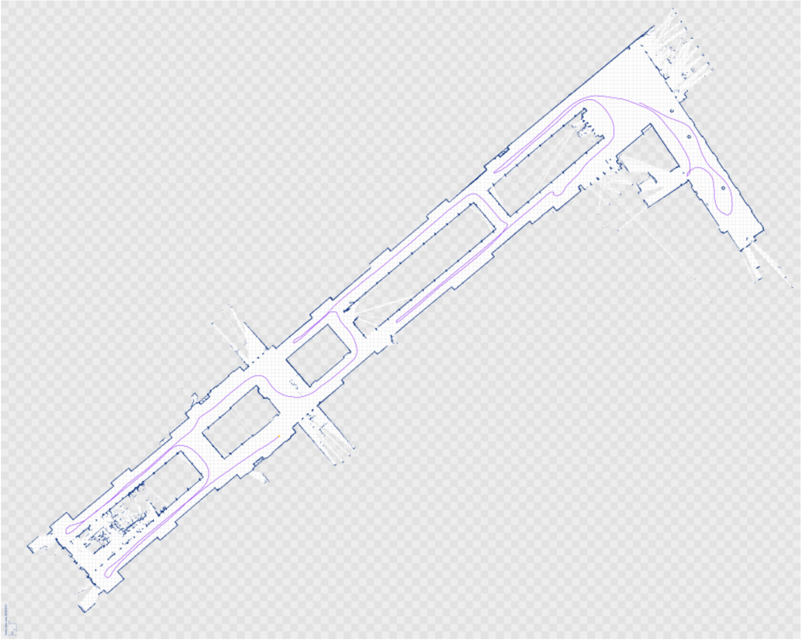

Figure 2: Large scale GeoTIFF Map from the 3rd floor of the University of Applied Sciences Upper

It creates an occupancy grid map using a LIDAR (Light Detecting and Ranging) System. The grid consists of cells which store the information if they are free space, an obstacle or unknown terrain. If the Robot starts exploration the map consists of only unknown terrain cells. If after a few scans the Robot detected obstacles it remarks the information in these cells. The cells before an obstacle are remarked as free space.

6.2. Exploration and Path Planning

The black marked cells are obstacles, the light grey cells are free space and the dark grey cells are unknown terrain. If there are obstacles in the map the Robot is able to estimate its position and its moving velocity relatively to these obstacles. Due to the precision of the laser scanner there is no odometry from the Robot required.

If the Robot is not remote controlled a second problem has to be solved. The Robot has to choose autonomously where to go next. To solve this problem the hector_exploration_planner [3] is used. The planner generates goals and paths to these goals. The hector_exploration_planner package is a library that can be used inside a ROS node.

As described in [4] a path will be generated by calculating the cost to reach a close frontier. A Frontier is a cell in the occupancy grid map that is marked as free space and has a neighboring cell that is marked as unknown terrain. Costs are the distance to the frontier and the safety of reaching the frontier. With a weighting factor it can be adjusted how much a safer path is preferred over a shorter one.

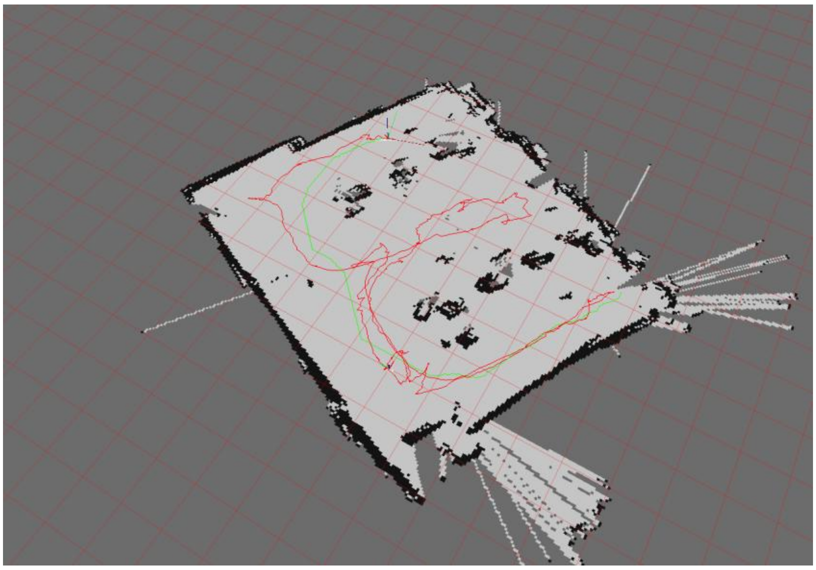

Figure 3: Exploration of MIK-Laboratory: The planner will generate a path from the robot's current position (red) to a desired goal pose (green)

The map submitted after each mission will generated with the hector_geotiff ROS package. It provides a node that can be used to save occupancy grid map, robot trajectory and object of interest data to RoboCupRescue compliant GeoTiff images. [12]

6.3. 3D-Mapping

A popular approach to modeling environments in 3D is to use a grid of cubic volumes of equal size (voxels) to discretize the mapped area. During the ROS Summer School in Graz (2012) the researchers have developed 3D-Mapping software. The software stack is based on the OctoMap, which was developed as a probabilistic, flexible and compact 3D Map representation for robotic systems from the University of Freiburg, Department of Computer Science. [13]

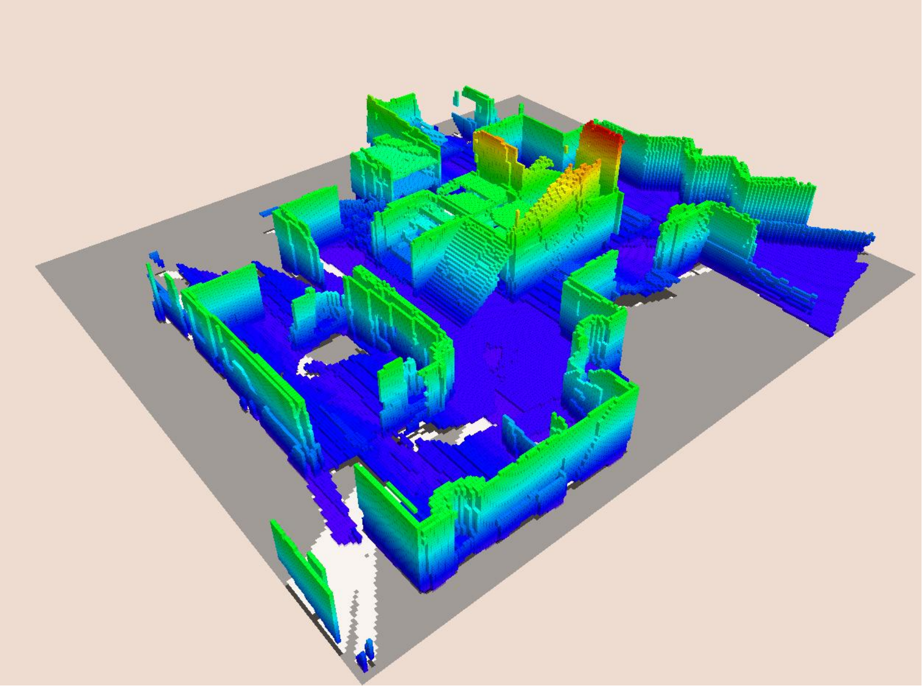

Figure 4: 3D-Map representation on the Octomap library

7. Sensors for Navigation and Localization

7.1 IMU:

In order to detect the position and the attitude of the robot an inertial measurement unit, so called IMU, is used. The IMU which is employed in the robot, is the *MTi* from the company *Xsens* [6]. Figure 5 shows a picture of the *MTi* and *ADIS13364* from *Analog Devices*.

Figure 5 IMU from Xsens MTi and Analog Devices

The *MTi* consists of three accelerometers, to determine the acceleration in the three axes and three rate sensors, to detect the attitude. Additionally three magnet sensors are used to achieve the direction of the earth magnetic field for referencing the sensor. The sensor has a built in Kalman-filter to provide drift free information of the attitude, calibrated acceleration and magnetic field information. Data can be transmitted either via USB or RS232. In this case the sensor is connected via USB to a wireless LAN router which transmits the data to the operator station where the data is processed by a program written in LabView. Determining the driven path is done by integrating the information of the acceleration twice.
The sensor also gives the value of the current altitude. It is very useful for the remote controlled mode, because the motion of the robot can be controlled easier. Furthermore the altitude is necessary for calculating the distance values of the laser-scanner.

The new rescue robot is equipped with the high precision tri-axis inertial sensor (ADIS13364) from the company Analog Devices [14].

7.2 2D-Laser Scanner:

The UGVs are equipped with different LIDAR systems from Hokuyo Ltd. [5]. For large scale mapping the Hokuyo UTM30-LX is used to map for example the University of Applied Sciences Upper Austria, see Figure 2. For the RoboCup Rescue League the robots are equipped with UBG-04LX-F01 and the low cost URG-04LX-UG01 which are mounted on a pan/tilt unit in front of the robot chassis.

7.3 Asus Xtion Pro:

Each rescue robot is equipped with the ASUS Xtion Pro live, which generates 3D point clouds. The RGB-D camera is used to obtain a complete 3D model from a set of point clouds or calibrated images. The environment perception is necessary for driving in uncertain terrain, to analyze, if the terrain is traversable and of course to rectify the position of the victims.

8. Sensors for Victim Identification

8.1. Vision System

The main task in the Rescue League is to detect victim, draw a map of possible ways into and out of the building and send important information to search and rescue teams. The victims are simulated by dolls which show signs of life as moving, body heat, speaking or least breathing. Closed to the victims hazmat labels and eye charts are placed. So the robot should be able to detect them and send the information to the rescue team.

For the detection of these hazmat labels and QR-Codes the robots are using simple USB cameras and a database with different hazmat labels was created. With the use of the OpenCV library and other open-source tools it is possible to try out many different algorithms for computer vision [19].

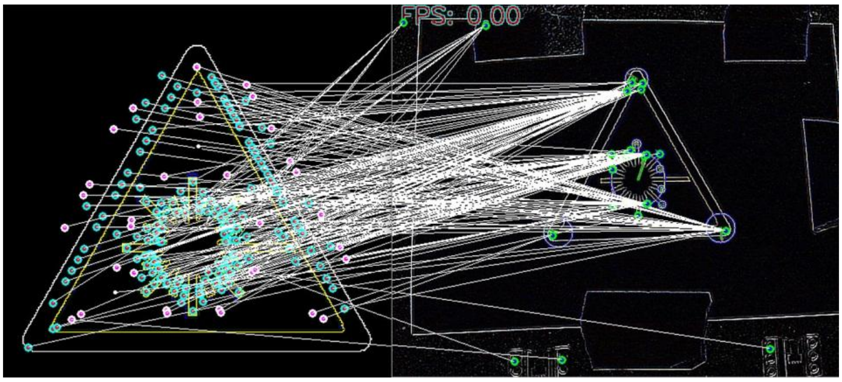

Figure 6: Detection of Hazmat Labels

8.2. Thermo Vision System

The core of thermo vision system is the *FLIR* [8] infrared thermo camera *A320* which works in a range of 7.5µm up to 13µm wavelength. The camera uses an uncooled micro bolometer to detect the infrared radiation which is emitted by the objects in the observed area. The A320 camera works at 30 fps which also allows detecting the movement of objects precisely.

Figure 7: FLIR Thermo vision with A320 and A65

The data of the sampled information is sent via wireless LAN to the main computer where a program analyses the live stream.

Figure 8: Infrared and RGB picture of doll detection

It is planned to implement a smart algorithm which is supposed to detect interesting objects such as victims automatically. Therefore the picture is scanned for conspicuous areas. The objects in the picture should be found using the temperature information. On one hand victims can be classified by a certain body temperature on the other hand dangerous heat sources can be localized. The next step in the development process will be acquiring detailed information about the location of the object and to mark it as an interesting point in the created map. The distance between the robot and the detected object will be calculated using a "depth of focus" algorithm.
For the final solution algorithms are supposed to combine the pictures and their information of the different cameras.

8.3. Other Sensors for Victim Identification

Acoustic:
For the detection of acoustic signals the microphone *130D20* from *PCB Piezotronics* [9] is used. It is a pre-polarized condenser microphone with a built in pre amplifier. The range of measurable frequency is from 20 Hz up to 15 kHz which is basically the typical audible range of human. It is built into a very robust steel casing with a BNC connector on the rear side. The incoming signal is first filtered by a digital high pass filter to get rid of noise and then the signal is Fourier-transformed to get the frequency

spectrum. The microphone is mounted on the top of the robotic arm close to the cameras.

Gas-Sensor

For detecting carbon dioxide the sensor the CDM4161A CO2 unit from Unitronic [10] is used. This unit uses the TGS 4161 sensor from Figaro. The CO2 sensitive element consists of a solid electrolyte formed between two electrodes, together with a printed heater substrate. By monitoring the change in EMF generated between the two electrodes, it is possible to measure CO2 gas concentration. This highly miniaturized pre-calibrated CO2 sensor unit has low power consumption and no maintenance is required. Furthermore its dependency of humidity is quiet low and its range goes from 350 ppm up to 10.000 ppm. The measuring board CDM4161A is just using a range of 400 ppm to 4000 ppm. As output the sensor unit provides an analog voltage level from 0.4 V to 4 V which is proportional to the carbon dioxide concentration in the air. Then this value is transformed into a ppm-value which denotes one part carbon dioxide per 10^6 parts of air. The sensor is also mounted on the top of the robotic arm.

Figure 9: **CDM4161 CO2-Sensor**

9. Robot Locomotion

9.1 Tracked Vehicle – MARK12

The locomotion of mobile robots in uneven terrain is one of the most difficult demands on the system. On one hand, as an outdoor robot it has to be fast and flexible on the other hand the vehicle has to deal with rough underground such as stones, gravel or stairs. Other important requirements are that the whole system is robust and consists of lightweight construction to reduce the energy consumption.

The MARK12 UGV has four active flippers, where every flipper is driven by two brushless motors, one motor drives the main pulley wheel, the second one is supporting the cantilever. The drive system basically consists of four pulley belts which are driven separately. Additionally the two belts (left and right side) and the middle belts can rotate individually. This is important for tasks like driving over uneven underground and climbing stairs. The body of the vehicle basically consists of an aluminum frame and the gaps, which are for reducing weight, are covered with carbon composite sheets.

Figure 10: MARK12 on an exhibition in Wels

9.2 Four- and Six-Wheel Drive

The main attention of this work describes the development of a compact, robust and efficient in energy consumption. Both UGVs are based on the commercially available "Wild Thumper" and the RC Monstertruck "Bullet MT Flux 4WD" and a very fast in motion. The UGV - Unmanned Ground Vehicle systems are very lightweight (5 kg) and small in size but limited to implement more sensors and to drive in uneven terrain.

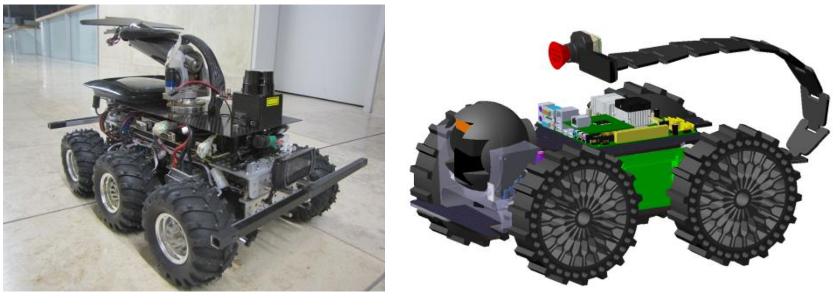

Figure 11: Wild Thumper 6WD and Bullet MT Flux 4WD

10. Other Mechanism

10.1 Robot arm for manipulation

The main target of this project was to develop a robot arm for the rescue robot to grab and move things like small bottles or cubes with an approximately weight of 0.5 kilograms. The objects can be placed everywhere on the area and the arm should be able to get them also from plates in a height of up to 1.2 meters.

To increase the stability and reduce the weight of the structure, materials like aluminum alloy and carbon are used. The three main parts are chosen as U-Shapes to have easy manufacturing and high reinforcement. To keep the flexibility of the robot we decided to construct the arm with three main axes, so the arm is really compact when it is not used.

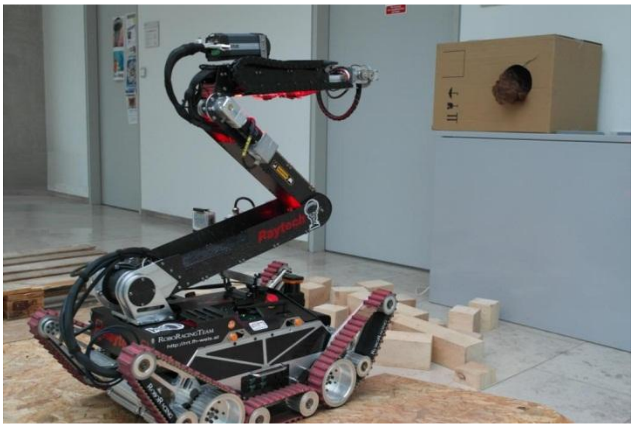

Figure 12: 7-DOF robot arm

In complete the robot arm has 7 axes which include one linear gear. The axes are driven by Maxon[1] engines and controlled by seven ELMO controllers.

Figure 13: ELMO Controller

The arm and the robot can be easily assembled by a KIPP clamping tool[2] for transporting the rescue robot.

The robotic arm was also analyzed with the Finite Element Analysis. There we simulated the situation when the gripper picks up an object. It is possible that the gripper is not in the best position to grab the object, so we chose a diagonal force which we applied to the gripper adapter.

When we apply a diagonal force of 10N to the gripper adapter, than we can see that the robotic arm is altered about 0.5 mm. So the robotic arm is easily capable of carrying items with a weight of 0.5 kg, see Figure 14.

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[1] http://www.maxonmotor.com/

[2] http://www.kipp.com/

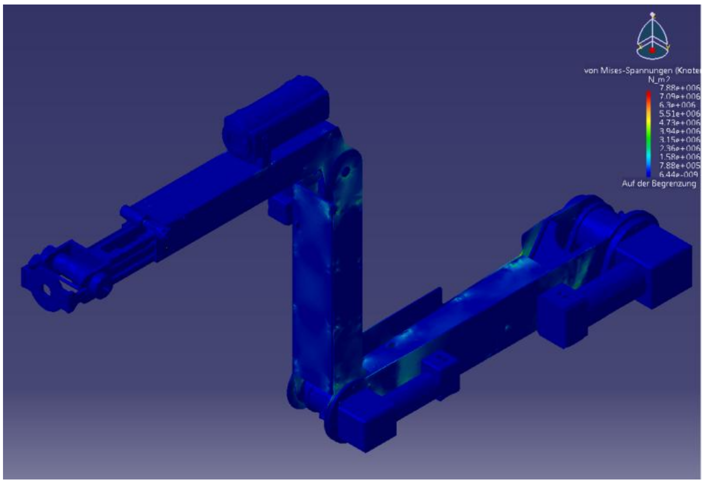

Figure 14: Finite Element Analysis of the arm with 10N

10.2. Teleoperation of the robot arm

The motion of the robot arm is controlled by a robot arm model which is connected to the operator station. The dimensions of the robot arm model are proportional to the robot arm. Therefore the behavior of these two systems is similar and the movement can be transferred. There are seven degrees of freedom which can be apportioned among seven joints - six rotator joints and one translational joint. The translational movement is performed by a linear drive, which can be controlled with two pushbutton switches. They are mounted on the handhold of the robot arm model. The following figure is showing a schematic drawing of the seven joints.

To ensure better handling, a magnet is linked the forearm of the operator to the model. Grabbing the handhold, the operator can easily lead the model. The gripper can also be controlled by two pushbutton switches on the handhold.

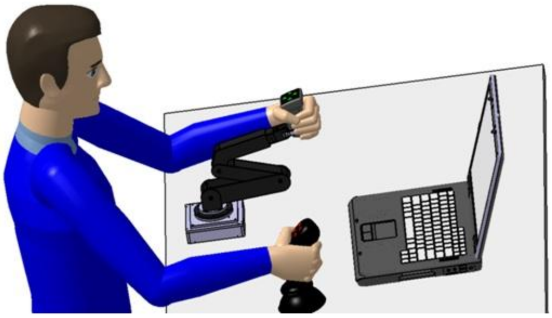

Figure 15: Teleoperation of the robot arm

The angels of the joints are measured by 3-way potentiometers. The first rotary joint is implemented with a polymer slewing ring bearing of IGUS®[3] and the linear movement is performed by a Faulhaber®[4] miniature DC motor and a Hydon-Kerk®[5] leadscrew.
The electronic contains an Atmel AVR XMega microcontroller which communicates with the operator station via USB to UART bridge. It controls the linear movement, the gripper and it converts the data of the potentiometers with 12 bit ADCs and transfers them to the operator station.

10.3. UAV

The design concept of the quadrocopter consists of a carbon frame with eight arms. Each of these arms is fixed to the inner cube through a special connector system which guaranties a maximum of flexibility and ease of transport. The cube of quadrocopter is divided into two levels. The flight control system and the entire data transmission system to the ground station are located on the lower level of the cube. The upper level serves as a mounting and flight compensation for camera, laser range finder and PIKO ITX board. So a flexible transformation is possible because the two levels are only connected to each other by a few plugs and screws. The previously imaginable applications are to equip the quadrocopter with a heat-or high-definition camera. It is also possible to install other devices such as transmitters and network devices to locate missing people in disaster areas and maintain communication.

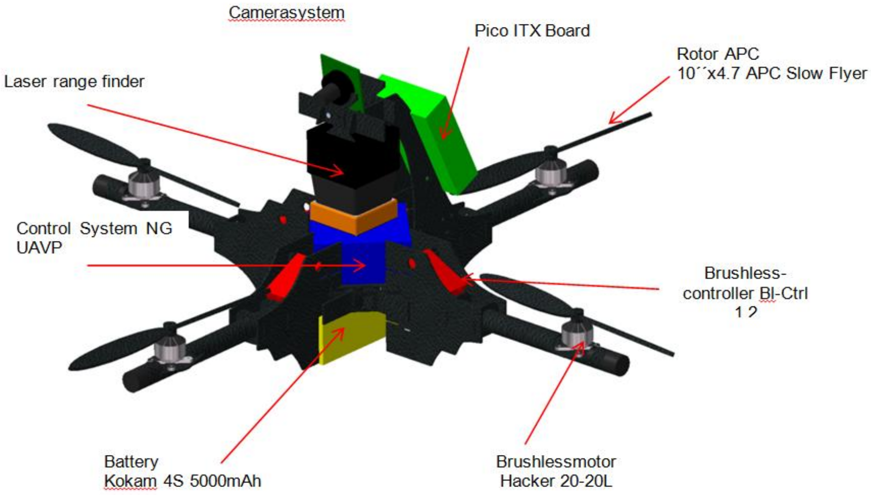

Figure 16: Self developed UAV

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[3] http://www.igus.de/

[4] http://www.faulhaber.com/

[5] http://www.haydonkerk.de/

10.4. Flexible hardware structure

The complete hardware structure is shown in Figure 17. The control board, a self-developed modular electronic system, controls all hardware components. This separation simplifies the testing methods and gives the structure more flexibility. The intrinsic actuators, all motors for locomotion and for the robot arm, and all intrinsic sensors, as ultrasonic sensors, absolute encoders, CO2-Sensor and one IMU (ADIS16364), for leveling the pan/tilt system, are connected to the electronic board. Most of the extrinsic sensors are connected to a separate on-board computer (Zotac Z65 Mainboard with Intel i7), which is equipped with Intel i7-processor.

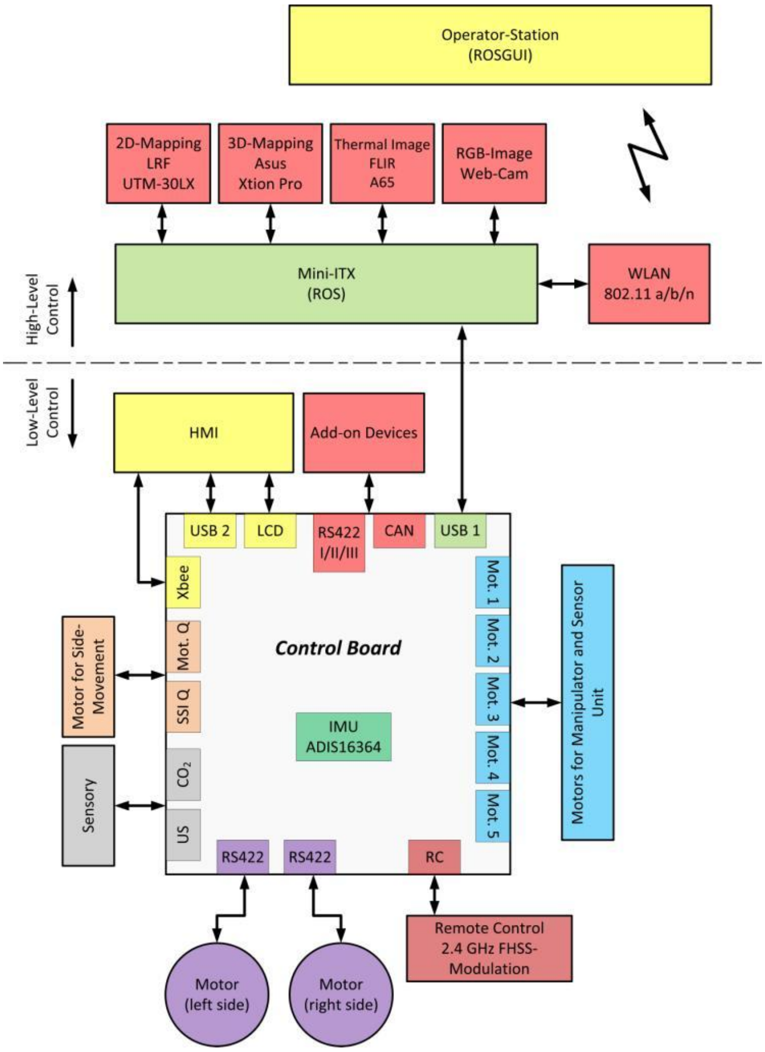

Figure 17: Hardware Structure

10.5. New Approach for Rescue Robot – Black Scorpion I and II

A novel tracked mechanism for sideways motion was developed at Osaka University in September 2011 [16, 17, 18]. The robot can 'turn on a dime', or more correctly, it doesn't need to turn at all. The unique Omni-Ball drive enables it to move in any direction in its plane of operation, and can make those moves almost instantaneously. The Omni-Crawler approach will definitely be a significant benefit in some applications that can be improved by its capabilities, and some applications that were previously impossible.

Figure 18: Drawing of the complete robot Black Scorpion I

Both systems will be presented the first time at RoboCup German Open 2013 in Magdeburg (GER) and RoboCup World Championship 2013 in Eindhoven (NED).

Figure 19: Drawing of Black Scorpion II with an Omni View Sensor System

11. Team Training for Operation (Human Factors)

The navigation of the rescue robot in our real disaster environment, which is shown in Figure 20, requires full knowledge of the function of the robot. So the remote controlling system requires a special training and practice for the operator to navigate the robot through the arena. Furthermore a large amount of practicing is necessary to control the 4 chain disk drives. Also the manipulation of the robot arm has to be learned by the operator. The team members are responsible for their contributions and to guarantee an accurate function of the developed algorithms. In the last month competitions are planned between the team members to in order to train operators for the RoboCup Championship. In the next few weeks, the RRT-Team will get a new test arena, where all missions (yellow, orange, red, blue and black arena) can be tested.

Figure 20: **USAR**[6] **Test Arena**

12. Possibility for Practical Application to Real Disaster Site

The robotic system is suited to support rescue team for allocating human victims, fire and gas in the case of a real disaster. It is supposed to replace humans in dangerous situations. The motion system, the robotic arm and the new rescue robots, which are mentioned above, allow to explore the operational area and detecting victims and dangerous situations

The team is in contact with fire fighting stations in the City Wels and with the company ROSENBAUER Group which is one of the world's largest manufacturers of fire fighting vehicles and after the competition we have to present the prototype of our

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[6] Urban Search and Rescue

rescue robot. With its wide range of municipal fire fighting vehicles we expect to force the development of our robot.

Furthermore we have projects with Progenox Ldt., which are working in the field of robotic for defence and homeland security.

13. System Cost

Name	**Part**	**Price in €**	**Nr.**	**Price Total in €**
Robot Base - production	LKR Ranshofen	12.500		12.500
Motion System	Haberkorn - Gears, drive belts	200	4	800
Robot Body	CFK-Carbo Tech	579	1	579
Accumulator	LiPO 25,9 V, 10AH	260	2	520
Laser Range Finder	Hokuyo UR-04LX-F01	2.280	1	2.280
WLAN Router	D-Link 635	60	1	60
Thermo camera	FLIR A320	10.500	1	10.500
Drive-Motors	Faulhaber 3242G024	240	8	1.920
Control System	National Instruments NI-CVS		1	sponsoring
	NI Single Board RIO		1	sponsoring
IMU	Xsens – Inertial Measurement Unit	2.100	1	2.100
Motion Control	Elmo-SimplIQ TRIO	1.000	5	5.000
Acoustic Sensor	CAE - Microphone	365	1	365
Sonic Sensor	Devantech SRF 10	51	4	204
Temperature Sensor	TPA 81	75	1	75
CO2-Sensor	Unitronic CDM 4161	42	2	84
Other mechanic parts	Bearings, Screws, Switches,			500
Fire-Wire cameras	Unibrain	100	3	300
Laptop	HP Compaq 8510p	1.800	1	1.800
Robot Arm- production	LKR Ranshofen			sponsoring
Arm Tubes	CFK-Carbon Scout	200	1	200
Motors for Robot Arm	Faulhaber 3242G024	200	6	1.200
Other mechanic parts for the Robot Arm	Mädler – Gears RS-Components, Conrad			Ca. 1.500
Sum Total				**42.600,00**

Table 2. System Cost of MARK12

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