



RoboCup2005

Rescue Robot League Competition

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RoboCupRescue - Robot League Team Team Deutschland1 (Germany)

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Abstract. After the second place in RoboCup Rescue 2004, a new version of the mobile robot Kurt3D was developed in our groups during the last year [1]. The key innovation of this system lies in the capability for autonomous or operator-assisted 6D SLAM (simultaneous localization and mapping) and 3D map generation of natural scenes. Hence, Kurt3D already meets the basic requirement regarding urban search and rescue. For the rescue robot league competition, it is additionally configured with dedicated state-of-the-art equipment e.g. infrared camera and CO₂-sensor. The robot and the operator station are rather compact and easy to set up. The operator uses a joystick as a remote control for the robot and can watch a live video of the scene where the robot drives. Data are transmitted via wireless LAN. A 3D laser scanner, which is mounted on an outdoor variant of Kurt3D, is used as the main sensor for map generation as well as for navigation and localization. The whole system has been used with a proven record of success for different tasks of map building, so that we are confident of managing the rescue robot league competition, too.

Introduction

Our approach to the rescue robot league competition is based on Kurt3D – an unique system that was developed at the Fraunhofer Institute for Autonomous Intelligent Systems during the last three years and upgraded at our groups during the last months.

The goal of this research was to have an affordable autonomous mobile robot for indoor and/or outdoor environments that is able to generate 3D geometry maps of natural scenes from scratch. It should work completely autonomously, i.e., with or without manual control, with no landmarks or beacons, not only on flat or horizontal floors. The motivation was the hypothesis that reliable and “cheap” 3D information would be badly needed for advancing robotics research as well as for advancing service robotics applications.

The approach to achieve the R&D goals was to start from existing, related but stand-alone results of previous R&D (namely, the KURT2 robot platform, the 3D laser scanner, a method for high-speed robot control, and a method for 6D SLAM), and integrate them in terms of hardware and software into a new, unique system. Kurt3D inherits by the integration the distinctive features of these building blocks, and adds some features useful for the purpose, but not previously available, such as the possibility of manual wireless joystick control.

Kurt3D seems already well suited to go into hazardous areas as such at RoboCup Rescue. We therefore focused on what enhancements must be done to use such a mobile robot under those conditions. We also assumed that getting the best possible sensor information about destructed areas is the crucial point and that especially high quality distance measurements and a complete 3D-model of the scene are most important. Therefore, we did not put too much effort in detecting autonomously specific objects or casualties. This should at a first step lie mainly on the human operator of Kurt3D.

1. Team Members and Their Contributions

Among other people that are involved in the preparations for the RoboCup2005 our team consists of these members:

- Matthias Hennig: Tele-operation, remote visualization modules, victim identification
- Kai Lingemann: 2D localization, 3D data processing
- Walter Nowak: Victim identification
- Andreas Nüchter: 3D data processing and visualization scan registration. i.e., 6D SLAM, 3D object classification and recognition
- Kai Pervözl: Mechanical design, camera and servo control module
- Hartmut Surmann: Robot- and laser control software, real-time modules, Tele-operation, 2D localization
- Thomas Wisspeintner: Platform development
- Oliver Wulf: 3D laser scanner, 3D data processing

- N. N. Participating students (University of Osnabrück)

Among other people that are involved in the preparations for the RoboCup 2005 these people must be emphasized for their roles in the project:

- Thomas Christaller: Director of AIS, promoter of AIS's RoboCup midsize league team for many years and initiator of the new RoboCup Rescue project, speaker of the DFG Priority Programme 1125 (RoboCup)
- Joachim Hertzberg: Head of Knowledge-Based Systems group at University of Osnabrück, scientific advisor
- Bernado Wagner: Head of Real Time Systems group at University of Hanover, scientific advisor

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



Fig. 1. Left: The mobile robot platform Kurt3D outdoor version. Right: . The 3D laser scanner. The scanner rotates around the vertical axis. The technical basis is a SICK 2D laser range finder (LMS-200).

Kurt3D (Fig. 1, left) is a mobile robot platform with a size of 45 cm (length) x 33 cm (width) x 29 cm (height) and a weight of 15.6 kg (including batteries and laptop). Equipped with the 3D laser range finder the height increases to 50 cm and the weight to 24 kg.

Kurt3D is available in two variants, an indoor edition with a maximum velocity of 5.2 m/s (autonomously controlled 4.0 m/s) and an outdoor edition with a maximum velocity of 1.5 m/s.

Two 90W motors are used to power the wheels. Kurt3D operates for about 4 hours with one battery (28 NiMH cells, capacity: 4500 mAh) charge. An embedded 16-Bit CMOS microcontroller is used to control the motors.

The higher layers of the software run on an on-board laptop PC (Pentium IV 1.4 GHz with 768 MB RAM), which is connected to the microcontroller via CAN (controller area network) – a widely used standard, for instance in the automotive industry.

The tele-operation will be done with another laptop (3 kg) and a joystick. Only one operator is needed to carry the entire equipment with a maximum weight of 26 kg. The set-up lasts less than 10 minutes and consists of:

- connecting a laptop and wireless LAN with the robot,
- detaching fixed screws, and
- booting Linux on both laptops for the robot and the operator.

3. Communications

Wireless LAN in the 5 GHz range according to IEEE 802.11A specification is used for the communication with the robot. The power is limited to 50 mW. Special antennas can be used to ensure the optimal transmission.

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Frequency	Channel/Band	Power (mW)
5.0 GHz – 802.11a	selectable	50

4. Control Method and Human-Robot Interface

The robot transmits its sensor information during its exploration via wireless LAN: data gathered by a laser scanner (cf. Sec. 6), images of 2 video cameras, and noises captured by a microphone (cf. Sec. 7), temperature images captured with an infrared camera and CO₂ with a CO₂-sensor. The robot is in principle able to drive autonomously, but this feature will be used only in cases, when the communication to the robot is interrupted. Under normal circumstances, the robot's locomotion is controlled by teleoperation with the means of a joystick. The operator is also capable to mark the location of victims, which he perceives on the screen, within the image.

5. Map generation/printing

Our method of map generation builds essentially on the 3D laser scanner [12] as the key sensor, which is described in more detail in the subsequent Sec. 6. In fact, SLAM (simultaneous localization and mapping) is done, so the separation between describing map generation and localization is only followed here to adhere to the given structure

of this team description document. The distinctive feature of our maps is that they consist of true 3D data (laser scan points) and can be built in full autonomy [2].

For the purpose of sketching the mapping procedure in isolation, assume there is a 3D laser scanner that delivers as an output of one measurement a cloud of points representing 3D distance measurements over, 360deg at a resolution of one degree. The 3D map building works by a sequence of

1. 3D scanning the scene from the current pose while standing still,
2. Registering the latest scan with the previous 3D map (initially empty),
3. Determining the next accessible view pose to steer to,
4. Navigating to this pose,
5. Going back to item 1., unless some termination condition is fulfilled.

The complete process has been demonstrated to work on-line on a mobile robot in full autonomy [3], but the Kurt3D robot can also be operated under manual control (joystick) in the view pose planning and navigation part. As an example, Fig. 2 shows a 3D laser range scan of a scene within the orange arena.



Fig. 2. Single 3D laser range scan inside the orange arena

The basic registration is a variant of the ICP algorithm [5], made efficient for use on-line on-board the robot by reduction of the point clouds and efficient representation (approximate kD trees) of the remaining point set [2].

The main difference between previous ICP based mapping approaches and our algorithms is the use of semantic information. Surface attributes are extracted and incorporated in a forest of search trees in order to associate the data, i.e., to establish correspondences. The basic idea of labelling 3D points with semantic information is to use the gradient between neighbouring points to differ between three categories, i.e., floor-, object- and ceiling-points. Fig. 4 shows a 3D map containing semantic information.

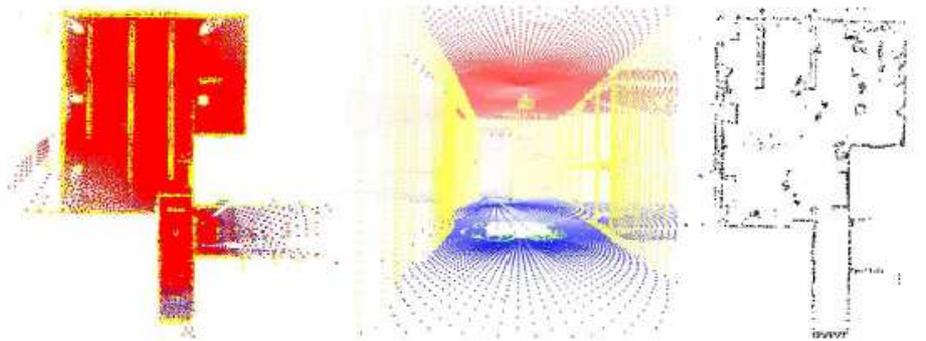


Fig. 3. Results of a semantic based mapping experiment. Left: 3D point cloud (top view). Middle: Some view of the points. Right: A floor plan extracted from the 3D model, i.e., only points with a height of $125\text{ cm} \pm 15\text{ cm}$ are drawn.

The accuracy of the maps is limited by two factors, first, the accuracy of the laser scanner, and second, any remaining registration errors. Based on the accuracy of the SICK scanner employed, each 3D point has a resolution of 5 cm within the measurement ranges involved here. Online registration may in principle induce errors derived from miscalculations in the prior scan pose estimations. (The registration method of *simultaneous matching* [2] that we have developed to generate very accurate 3D maps is relatively computation intensive and could not be used on-board a robot in the rescue competition.) We have until now made only positive experiences with our on-line registration procedures in structured environments like the ones in the Rescue arenas. A work described in [6] gives some details about that.

One of the distinctive features of our registration approach is the fact that it works under translations in all three directions (x , y , z) and rotations in all three Euler angles (yaw, pitch and roll). The respective version of the simultaneous localization and mapping is termed 6D SLAM, emphasizing the fact that, different to SLAM approaches that assume the robot to sit on a plane surface and considering poses only in terms of three mathematical dimensions (x , y , θ), we can cope with poses in the full range of six mathematical dimensions possible for a robot in 3D space. This is crucially important for 3D geometry mapping if elevation (ramps) is present for the robot or if the robot may pitch or roll over ramps or over debris lying on the floor, as is to be expected in RoboCup Rescue scenarios. A video featuring a round trip of Kurt3D in AIS's robotics lab is available under [4].

There is a possibility for a human operator to highlight or clip 3D volumes in the 3D maps, for example to mark the place of victims.

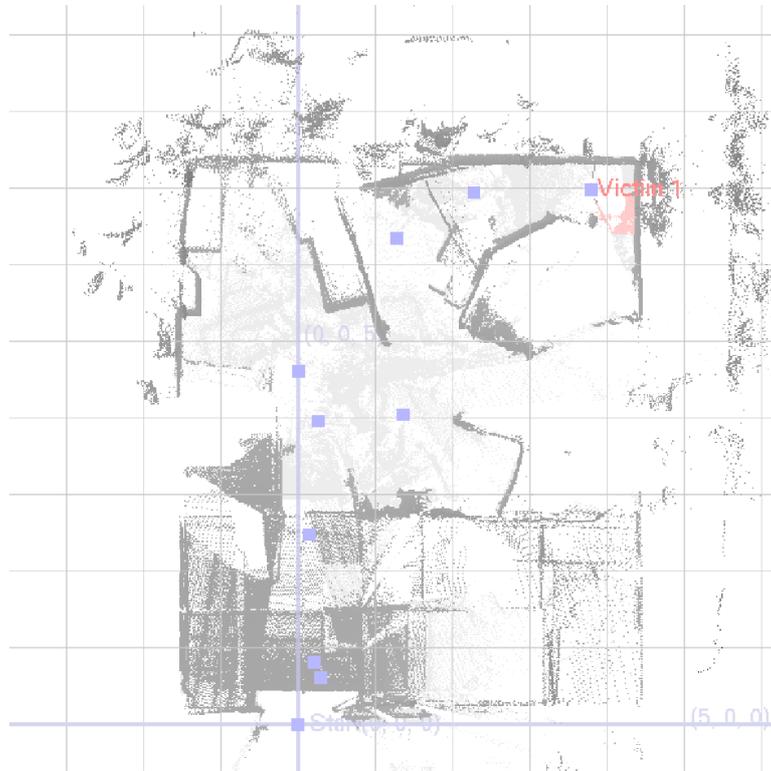


Fig. 4. Generated 3D map (top view) of RoboCup's 2004 orange arena with marked victim.

Using OpenGL, the point-based maps, as well as different varieties of meshes generated from them, are rendered and drawn on the screen from arbitrary perspectives. The user may navigate through the 3D scenes by way of a simple cursor control or a joystick control. Of course, arbitrary 2D views of the 3D maps may be printed as shown in Fig. 3 (right) or Fig. 4.

6. Sensors for Navigation and Localization

As remarked in the previous section, the main sensor for navigation and localization is the 3D laser scanner. As there is no commercial 3D laser range finder available that could be used for mobile robots, it is common practice to assemble 3D sensors out of a standard 2D scanner and additional motor drives [11, 12].

The scanner that is used is based on a SICK LMS 220 in combination with the RTS/ScanDrive developed at the University of Hannover. Different orientations of the 2D scanner in combination with different turning axes result in a number of possible scanning patterns. The scanning pattern that is most suitable for this rescue application is the yawing scan with a vertical 2D raw scan and rotation around the upright axis

(see Fig. 1). The yawing scan pattern results in the maximal possible field of view (360deg horizontal and 180deg vertical) and a uniform distribution of scan points.

As 3D laser scanner for autonomous search and rescue applications needs fast and accurate data acquisition in combination with low power consumption, the RTS/ScanDrive incorporates a number of improvements. One mechanical improvement is the ability to turn continuously, which is implemented by using slip rings for power and data connection to the 2D scanner. This leads to a homogeneous distribution of scan points and saves the energy and time that is needed for acceleration and deceleration of panning scanners. Another improvement that becomes more important with short scanning times of a few seconds is the compensation of systematic measurement errors. In this case the compensation is done by sensor analysis and hard real-time synchronization, using a Linux/RTAI operation system. These optimizations lead to scan times as short as 3.2s for a yawing scan with 1.5 deg. horizontal and 1 deg. vertical resolution (240x181 points). For details on the RTS/ScanDrive see [12].

Our quite extensive experience with the scanner, as well as experience from other groups using copies of it for generating, e.g., 3D models of urban streets, tells us that it is qualitatively within the range induced by the other sources of error and noise present in the process, i.e., measurement errors and robot pose estimation errors.

The registration and map building based on the 3D scanner data is described in the previous Sec. 5. The registration process needs as an input and a start value an estimation of the robot pose (in 6D for 6D SLAM) for the recent scan relative to the pose of the previous or some other earlier scan. This prior pose estimation is based on wheel encoder-based odometry for x , y , and θ values. We have example experience with tilt sensors for the pitch and roll angles as well as with gyros on the basic platform KURT2 [7], which could be used for estimating the three Euler angles. For estimating the 6D pose the scan registration matrix is used that represents all degrees of freedom. The x , y , and θ values are propagated in 6D by multiplying the resulting simplified matrix with the inverse of the full registration matrix of the previous scan.

This updated pose is then used as the basis for the pose tracking process up to the stop at the next scan pose. Compared to previous work [1], the main innovation is the use of the 360 deg. scanner as described above. In the 2004 Robocup Rescue competition we encountered that the overlap of two consecutive scans was sometimes too low, so that the operator had to intervene in the matching process. The new scanner reduces this problem, since it provides backward vision.

Other sensors (e.g., cameras) are available on the robot, but are used for navigation only.

7. Sensors for Victim Identification

It is investigated currently, which sensors are suitable for victim identification in addition to the marks set on the screen by the human operator (cf. Sec. 4). A microphone is used to detect human voices, and passive infrared sensors around the robot's body help to localize thermal sources like winking arms. Furthermore an infrared camera is

used to retrieve human body heat and one carbon dioxide sensor helps to verify the vital signs of the victims.

8. Robot Locomotion

Kurt3D outdoor edition as used in the RoboCup rescue league competition is based on KURT2, which is one of the standard platforms for robotics research at AIS. To increase mobility further mobile platforms are under development e.g. a special edition of the VolksBot [8] which is normally used in RoboCup midsize league and a new robot at RTS. Probably these platforms are not available in July, if so they would also be used. The new platforms should be able to climb stairs. All variants of KURT2 are buyable directly from the manufacturer KTO [9]. Firmware and operating software are developed, maintained and distributed under Open Source License at AIS [10]. A growing community of KURT2 users outside of AIS is involved in the further development.

The robot has six wheels, three on the left and three on the right side, which achieve progressive movement. The wheels are connected on each side by a toothed belt drive and are propelled by a high power engine with 90 W. Although being wheel-driven, the robot is steered using the differential drive model, which is primarily known from tracked vehicles.

9. Other Mechanisms

The key innovation of our system lies in the capability for autonomous or operator-assisted 6D SLAM and 3D map generation, as explained in Sec. 5 and 6.

10. Team Training for Operation (Human Factors)

The operator has to be trained to use a joystick control, which is similar to the user interface of flight simulator games for the PC. He or she must be in good physical condition, to be capable transporting the whole equipment (26 kg) to its destination.

11. Possibility for Practical Application to Real Disaster Site

We have until now no practical experiences with our system on a real disaster site. A priori, we think that both the integrated system (Kurt3D robot) and the 3D map construction equipment alone (3D scanner plus scanning, registration, rendering and interpretation software) would be robust enough for standing a field test, The robustness of our system was shown in the last year competition in Lissabone where we reached the second place. We are willing to submit our system to such a test.

Nevertheless, the Kurt3D robot has some obvious physical and geometrical limitations that are acceptable for the competition, but would have to be respected in a field test. For example, it is a relatively small, wheeled platform with restricted ground clearance. That does obviously limit its current range of practical applicability. On the other hand, we have very encouraging experiences with other applications regarding the reliability and robustness of the robot – the KURT robot was originally designed to evaluate sensor equipment for the inspection of sewer pipes. The new platforms which are just under development should be able to climb stairs and have more mobility than the current version of Kurt3D.

12. System Cost

The total cost of one robot, including some necessary minor parts that are not shown in the listing, is about 34.000 €. For the operator station a robust laptop PC with joystick and wireless LAN interface is recommended, which costs about 4.000 €. Further details about the system are given at [11].

TOTAL SYSTEM COST (per robot): 34.399 €

KEY PART NAME: KURT2 robot platform
MANUFACTURER: KTO
COST: 9.450 €
WEBSITE: <http://www.kurt2.de/>
DESCRIPTION/TIPS: The mobile robot platform.

KEY PART NAME: On-board laptop
MANUFACTURER: Panasonic CF-73
COST: 4.000 €
WEBSITE: <http://www.panasonic.com>
DESCRIPTION/TIPS: The control laptop, acquire and send sensor data, handle operator commands.

KEY PART NAME: 3D Laser Scanner
MANUFACTURER: SICK + RTS Hannover
COST: 10.000 €
WEBSITE: <http://www.rts.uni-hannover.de>
DESCRIPTION/TIPS: Used to take 3D scans ;-)

KEY PART NAME: Cameras with pan-tilt module
MANUFACTURER: Logitech + Fraunhofer Institute AIS (pan-tilt)
COST: 499,- €
DESCRIPTION/TIPS: Standard USB webcams on pan tilt module.

KEY PART NAME: Infrared camera
MANUFACTURER: Flir Systems
COST: 10.000,- €
WEBSITE: <http://www.flir.com/>
DESCRIPTION/TIPS: Enable the robot to detect body heat.

KEY PART NAME: Passive infrared sensors
MANUFACTURER: German Baumarkt
COST: 100,- €
DESCRIPTION/TIPS: Localize moving thermal sources.

KEY PART NAME: Carbon Dioxide Sensor
MANUFACTURER: Telaire
COST: 350,- €
WEBSITE: <http://www.telaire.com/>
DESCRIPTION/TIPS: Detect victims "breath".

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