RoboCup2004
Rescue Robot League Competition
Lisbon, Portugal
June 27 – July 5, 2004
www.robocup2004.pt

RoboCupRescue - Robot League Team KURT3D, Germany

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These students do their required practical studies at AIS.

Abstract. A mobile robot named KURT3D was developed at the Fraunhofer Institute for Autonomous Intelligent Systems during the last three years. 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. 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.

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 AIS 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

Our team, as it will be present at Lisbon, consists of these members:

- Matthias Hennig — Master student and programmer of the tele-operation and remote visualization modules, victim identification
- Kai Lingemann — PhD student and programmer of the 2D Localization, 3D data processing, 3D data visualization
- Andreas Nuechter — PhD student and programmer of the 3D data processing, 3D data visualization, scan registration (6D SLAM), path planning, 3D object classification and recognition
- Kai Pervoelz — Master student, designer of the cameras and programmer of the servo control, camera modules and texture mapping
- Hartmut Surmann — Senior researcher and architect of the soft- and hardware of KURT3D, programmer of the robot- and laser control software and the real-time

		modules, co-programmer of the camera and teleoperation modules
•	Kiran Raj Tiruchinapalli	Master Student and programmer of dedicated modules for victim identification
•	Rainer Worst	Senior researcher and project manager at AIS, developer of KURT3D's firmware and operating software, coordinator of KURT2-related activities

Among other people[1] that are involved in the preparations for the RoboCup2004, these persons 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 department ARC (Robot Control Architectures), Scientific Advisor for the project at AIS

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

Fig. 1. KURT3D inside the orange arena.

KURT3D (Fig. 1) 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 22.6 kg.

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[1] Special acknowledgements to Gustav Frohn for his construction of the laser scanner's tilt mechanism and to Sascha Odenthal of KTO for manufacturing the KURT3D platform.

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 2.4 GHz frequency range is used for the communication with the robot. The power is scalable from 50mW up to 500mW depending on the environment and application. Special antennas ensure the optimal transmission.

If required, radio communication in the 5 GHz range according to IEEE 802.11A is going to be used during the competition.

4. Control Method and Human-Robot Interface

The robot transmits various 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. 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 tele-operation 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 AIS 3D laser scanner [1] 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 distance measurements over, e.g., 180deg horizontally and 120deg vertically at a reasonable resolution. The 3D map building works by a sequence of

1. 3D scanning the scene from the current pose while sitting 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.

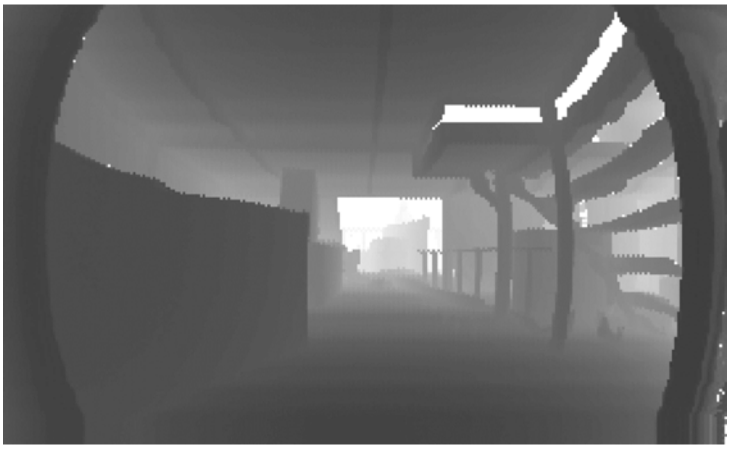

Fig. 2. Single 3D laser range scan inside the orange arena

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 (*k*D trees) of the remaining point set [2].

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 and every point is exact by about 1 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 no bad experiences with our on-line registration procedures in structured environments like the ones in the Rescue arenas. [6] gives some details on 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.

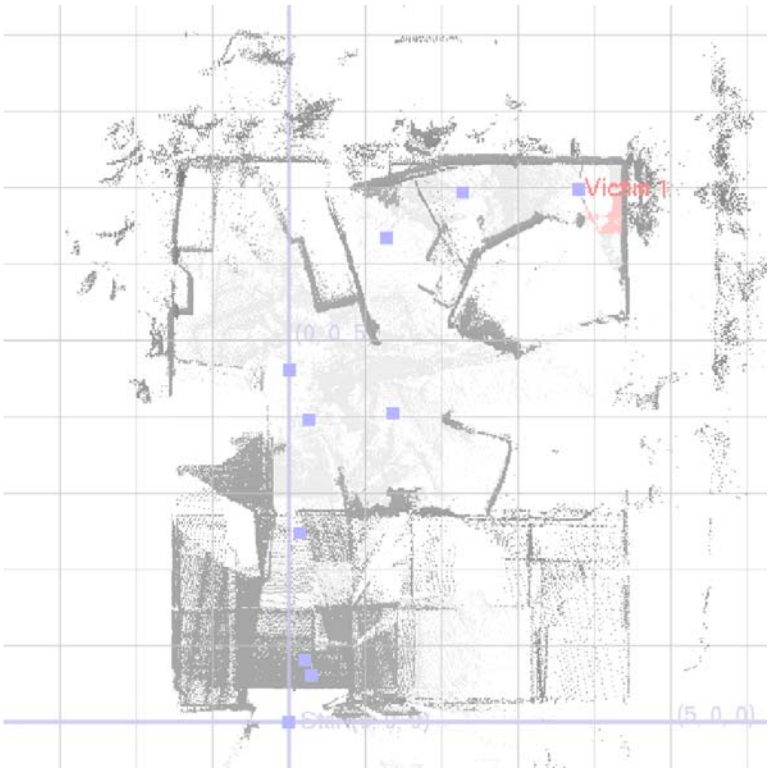

Fig. 3. Generated 2D map with marked victim.

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 curser control or a joystick control. Of course, arbitrary 2D views of the 3D maps may be printed as shown in Fig. 3.

6. Sensors for Navigation and Localization

As remarked in the previous section, the main sensor for navigation and localization is the AIS 3D laser scanner, which we have been using for some time now [1]. It executes a controlled pitch motion between the regular horizontal scans taken by the basic 2D laser scanner. The maximal pitch angle is 120 deg, with possible vertical resolutions of 128 or 256 lines. Together with the selectable resolutions of 181, 361, or 721 points per line over 180 deg horizontally given by the 2D scanner, a variety of selectable resolutions is offered. Depending on this resolution, a scan over the full scan area takes between 3.4 s and about 30 s. The measurement accuracy of the basic scanner is in the order of 1 cm for every single scan point. No quantitative results are known about the correctness of the angular resolutions (horizontal or vertical) of the scanner. Our quite extensive experience with the scanner, as well as experience from another group who use copies of it for generating 3D models of urban streets, tells 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.

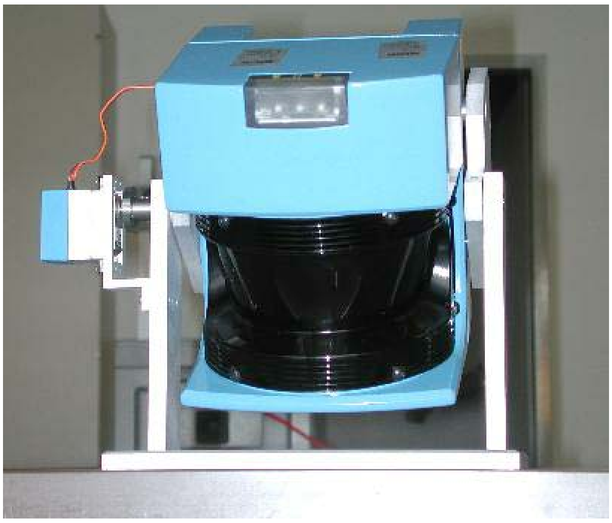

Fig. 4. The AIS 3D laser scanner, as based on a SICK LMS [1].

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, θ values and on incremental pose tracking with a relatively high frequency (up to 75 Hz) for the drives between scan points using the scanner in 2D mode fixed in the position aligned with the robot axis (horizontal if the robot sits on a horizontal floor). We have ample experience with tilt sensors for the pitch and roll angles as well as with gyros on the basic KURT2 platform [7], which could be used for estimating the three Euler angles; however, the high-frequent 2D pose tracking alone has until now given sufficient results. [2]

Based on the 6D pose estimation on the scan points, the scan registration process yields as a by-product a 6D correction of this estimation, namely, the inverse of the rotations and translations that were necessary to register the current scan taken at the current pose. This updated pose is then used as the basis for the pose tracking process up to the stop at the next scan pose.

Other sensors (e.g., cameras) are available on the robot, but are not in use for navigation and localization.

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.

8. Robot Locomotion

KURT3D outdoor edition as used in the RoboCup rescue league competition is based on KURT2 [8], which is one of the standard platforms for robotics research at AIS (another one is VolksBot used in RoboCup midsize league). 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. Everything else used on our system is nothing more than usage of the respective state of the art.

[2] Publications about this procedure are not yet available, as a patent application is pending.

10. Team Training for Operation (Human Factors)

The operator must 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, and we would be willing to submit our system to such a test, provided that the experience in the competition does not provide evidence to the contrary.

The KURT3D robot as is 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.

12. System Cost

Table 1. Key system components

Part	URL	Price
KURT2 platform	http://www.kurt2.de/	9.450 €
On-board laptop	http://www.microsite.panasonic.de/toughbooks/default.html	4.000 €
3D laser scanner	http://www.ais.fhg.de/ARC/3D/	8.500 €
CAN interface card	http://softing.com/en/communications/products/can/interface/pccard2.htm	850 €

The total cost of one robot, including some necessary minor parts that are not shown in table 1, is about 25.000 €. For the operator station a robust laptop PC with joystick and wireless LAN interface is recommended, which costs about 4.000 €. More details about the system are given at [11].

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