



## Team Information



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Name of vehicle:

Kurt3D



Picture of team leader:

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Team Description:

The mobile robot Kurt3D is developed at the University of Osnabrück. The development began at the Fraunhofer Institute for Autonomous Intelligent Systems (AiS) and is being continued at University of Osnabrück. The key innovation of this highly integrated, compact system lies in the capability for autonomous or operator-assisted 6D SLAM (simultaneous localization and mapping) and 3D map generation of natural scenes.



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6D SLAM (Simultaneous Localization and Mapping) or 6D Concurrent Localization and Mapping of mobile robots considers six dimensions for the robot pose, namely the  $x$ ,  $y$  and  $z$  coordinates and the roll, yaw and pitch angles. Robot motion and localization on natural surfaces, e.g., driving with a mobile robot outdoor, must regard these degrees of freedom.

*Map generation:* Our method of map generation is essentially based on the 3D laser scanner [1] as the key sensor. The distinctive feature of our maps is that they consist of true 3D data (laser scan points) and can be built completely automatically [2]. The 3D laser range finder (Fig. 1) is built on basis of a 2D range finder by extension of a mount and a standard servo motor [1]. The 2D laser range finder is



**Fig. 1: 3D laser scanner. Its technical basis is a SICK LMS-200.**

attached to the mount in the centre of rotation for achieving a controlled pitch motion. The servo is connected on the right side (Fig. 1). The 3D laser scanner operates for up to 5h (Scanner: 17 W, 20 NiMH cells with a capacity of 4500 mAh, Servo: 0.85 W, 4.5 V with batteries of 4500 mAh) on one battery pack. The area of  $180^\circ(\text{h}) \times 90^\circ(\text{max. } 120^\circ)(\text{v})$  is scanned with different horizontal (181, 361, 721) and vertical (128, 176, 256, 400, 500) resolutions. A plane with 181 data points is scanned in 13 ms by the 2D laser range finder (rotating mirror device). Planes with more data points, e.g., 361 or 721, duplicate or quadruplicate this time. Thus a scan with  $361 \times 176$  data points needs 4.5 seconds. In addition to the distance measurement the 3D laser range finder is capable of quantifying the amount of light returning to the scanner, resulting in a greyscale reflectance image of the scene. Scanning the environment with a mobile robot is done in a stop-scan-go fashion.

3D map building works by a sequence of

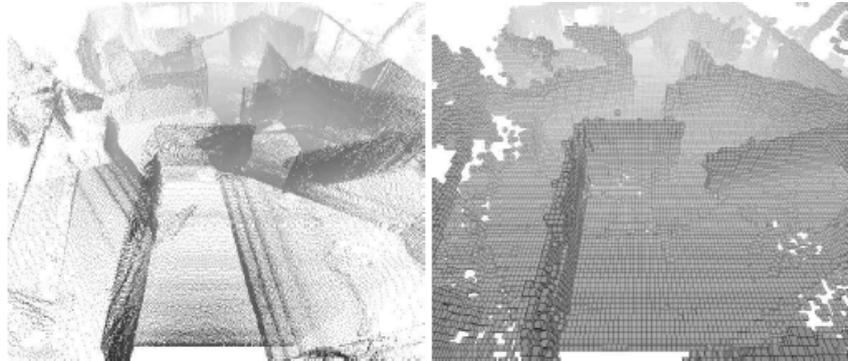
1. 3D scanning the scene from the current 6D pose,
2. registering the latest scan with the previous 3D map (initially empty),
3. determining the next accessible view pose to steer to,
4. navigating to this pose,
5. going back to step 1., unless some termination condition is fulfilled.

We use the well-known Iterative Closest Points (ICP) algorithm to calculate the registration transformation of 3D scans [3]. The ICP algorithm calculates iteratively the point correspondences. In each iteration step, the algorithm selects the closest points as correspondences and calculates the transformation, i.e., rotation



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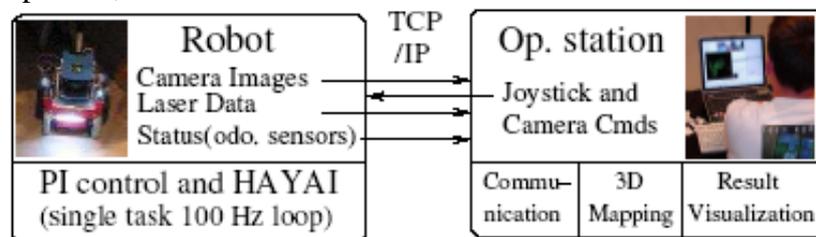
and translation, that minimizes the distances between corresponding points.



**Fig. 2: 3D maps generated from several 3D scans. Left: Point cloud. Right: Voxel (volume pixel) representation.**

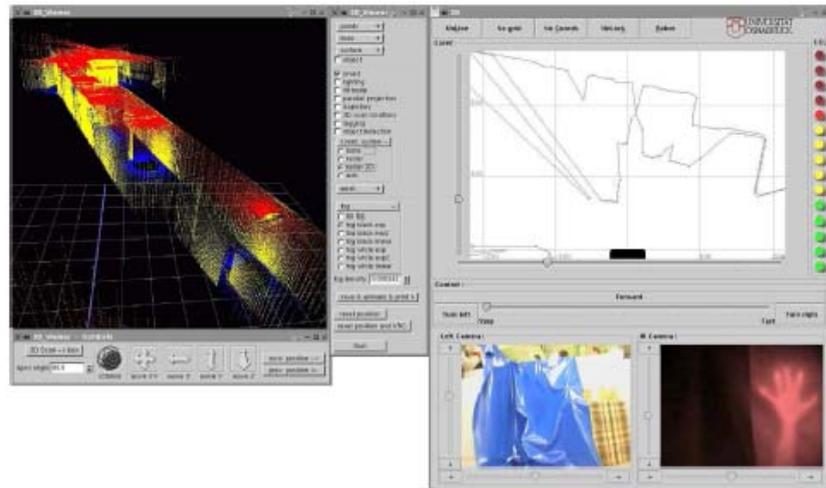
*Navigation:* The mobile robot Kurt3D provides two operation modes. Autonomous driving is used to navigate in areas where no wireless LAN is available. Hereby driving is based on drivable surface or lane detection and a fuzzy controller.

On the other hand, teleoperation is used to precisely steer the robot by a human operator from the base station. The base station consists of a Linux laptop and a WLAN antenna, conforming either to the IEEE 802.11A (5 GHz) or to IEEE 802.11B (2.4 GHz). To drive the robot, camera images from two cameras are transmitted. To improve situation awareness the cameras have been mounted on pan/tilt-units, thus the cameras overall apex angle is  $180^\circ(\text{h}) \times 120^\circ(\text{v})$  in analogy to the apex angle of the 3D scanner. To drive the robot in dark areas, light is attached to the cameras. In various experiments it turned out, that navigating a mobile robot is easier if the operator is provided by a map. Therefore, both the 3D map and the current 2D laser scan are presented to the operator. The odometry and a gyro are used to estimate the robot pose that is presented to the operator, too.



**Fig. 3: System Overview: The robot runs a 100 Hz loop for motorcontrol, scan processing, image encoding and transmission. The Kurt3D server executes three threads that are responsible for communicating, 3D mapping and result visualization. See [5] for details.**

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**Fig. 4:** The user interface for tele operation. The left part shows the 3D map; the right the current scan and camera images. For urban search and rescue operations the robot can be equipped with an additional infrared camera and a CO<sub>2</sub> sensor [6].

*Robot Locomotion:* Our robot is based on an outdoor variant of KURT2 [7]. Six wheels, three on the left and the rest on the right side, achieve progressive movement. They 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. Kurt3D operates for about 4 hours with one battery charge (20 NiMH cells, capacity: 4500 mAh) charge. The core of the robot is an Intel-Centrino-1400 MHz with 768 MB RAM and a Linux operating system. An embedded 16-Bit CMOS microcontroller is used to process commands to the motor. A CAN interface connects the laptop with the microcontroller.



**Fig.3:** The skid steered robot Kurt3D.

Sponsors:

University of Osnabrück

Selection of scenario:

urban



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