

C-ELROB 2009
Technical Paper
Team: University of Oulu

Antti Tikanmäki, Juha Röning

University of Oulu
Intelligent Systems Group
Robotics Group

sunday@ee.oulu.fi

Abstract

Robotics Group is a part of Intelligent Systems Group at the University of Oulu, dealing with research on embedded systems and robotic systems. The research includes mechanical, electronical and software architectures as well as sensor fusion, machine vision and intelligent control. The group concentrates on applying research results on real world challenges.

The navigation on our robot is based on position estimation and waypoint path execution. The robot is equipped with GPS, four laser scanners, an IMU (inertial measurement unit) and four cameras, including one Thermal camera. LadyBug spherical camera is used by onboard machine vision and one thermal camera and analog video camera are used for machine vision and direct remote operation of the robot.

Robot can be controlled directly or by sending GPS waypoints of desired route. Google Earth software is used as an user interface for routes and current global location of the robot. Machine vision algorithms running onboard are used to detect traversable area. Obstacle detection and avoidance are based on data fusion of laser scanners and machine vision, and local route recalculation. For the Elrob scenarios, robot will be equipped with several autonomous recognition and control methods that will provide desired functionalities. These include thermal image analysis, target (like intruder) following, route execution, and 3D environment mapping.

1 Mörri



Figure 1. Mörri

Mörri is a mobile outdoor robot developed and built at the University of Oulu. Custom-built chassis and body contains differential steering and 6 wheels on each side. Each side is driven by a 3kW brushless servo motor, with custom-made motor controller. Robot sends video images using an analog video link. Source of the image can be selected programmatically between normal camera, thermal camera and video output of the main computer.

Mörri is a modular platform for multi purpose applications. It has been developed at the University of Oulu, and all the mechanics and electronics parts have been designed by the group. Platform has been designed to be used in hard weather conditions, including temperature variation from -30 degrees up to 35 degrees, rain, snow and other extreme weather conditions (Figure 2). One major design issue has been to develop a low cost, easy to manufacture, and high performance platform, while keeping it as simple as possible to keep up easy maintenance and operation. In field robotics, fixing the robot outdoors is limited, thus the robot must be simple and easy to fix. The robot is also designed to be operated indoors, and it fits through doorways and use electric motors. With a small size, safety issues related to the robot harming humans and surroundings are also easier to handle.



Figure 2: Modular base (left), multi-purpose platform pulling trailer (right)

To gain easy and fast development, most of the robot's body parts are developed from standard 100x100mm 3mm thick aluminum profile. Motors are standard Towerpro 259Kv brushless DC motors (BLDC) (costs 49 dollars / motor). A standard bike chain is used for power transmission to all wheels. Gear reduction is 1:12, created in two phases, using primary gear reduction and chain gears. All wheels are active, and the middle wheels on both sides are 16mm lower than other wheels for improving steering in high friction like asphalt. With narrow width of a bottom of the robot (100mm), it will have better grip (as having more wheels) and it moves easier on rough environment like forests.

Custom made motor drivers and controller electronics are used for driving BLDC. The BLDC motors provides superior power to weight ratios as compared with brushed DC motors, and high currents can be used with a small size motor. The developed driver can provide up to 3 kW to each motor. The main reason for own custom driver and controller was a lack of commercially available products, but also the power effective control of brushless motors has been a subject of research.

The lower part of the robot is a stand-alone module (see Figure 2). It contains motor drivers and controllers, 16 Ah LiPo battery, and motors and gears. All are fitted to two 100x100mm aluminum profile. This base has an RS232 interface and custom made protocol is used. The motor controller is a custom made processor board containing Atmel AVR ATmega32 processor, including two brushless servo control and PID controls. To test drive a platform a radio modem can be connected directly to the serial port, and no additional computer is needed for remote driving.

The robot includes several sensors for autonomous operation. Several lasers help autonomous driving and obstacle avoidance, and stereo camera system including machine vision algorithms provide information of detected targets and traversability of ground. The development of the Mörri system began in August 2007 after first C-Elrob competition.

2 Autonomous Operations

2.1 Processing

The processing is done using a laptop. A Lenovo X60s with an Intel Core 2 Duo L7400 processor was selected as the computer for the robot. The computer boots Linux from an USB memory stick and there is no hard disk onboard. The custom made stripped Linux distribution can boot up in few seconds, which provides faster recovery in case of failure. During test periods there were no failures and system is considered as a robust.

Major sensor processing is included onboard and robot delivers refined information like detected targets using distributed software architecture called Property Service architecture (PSA) [1]. For tele-operation, control commands, route positions are sent using the PSA protocol.

Most parts of the software are based on Maahinen [2] in C-elrob 2007 and previous version of Mörri in M-Elrob 2008 version [3] of the robot with some further improvements. This includes sensor interfaces, data descriptions, machine vision and control interfaces. Essential part of the architecture is the Markers, used to describe output of various sensors in unified format and providing data fusion.

After success in M-Elrob 2008 competition (by winning Camp-security scenario) several improvements to the software have been made.

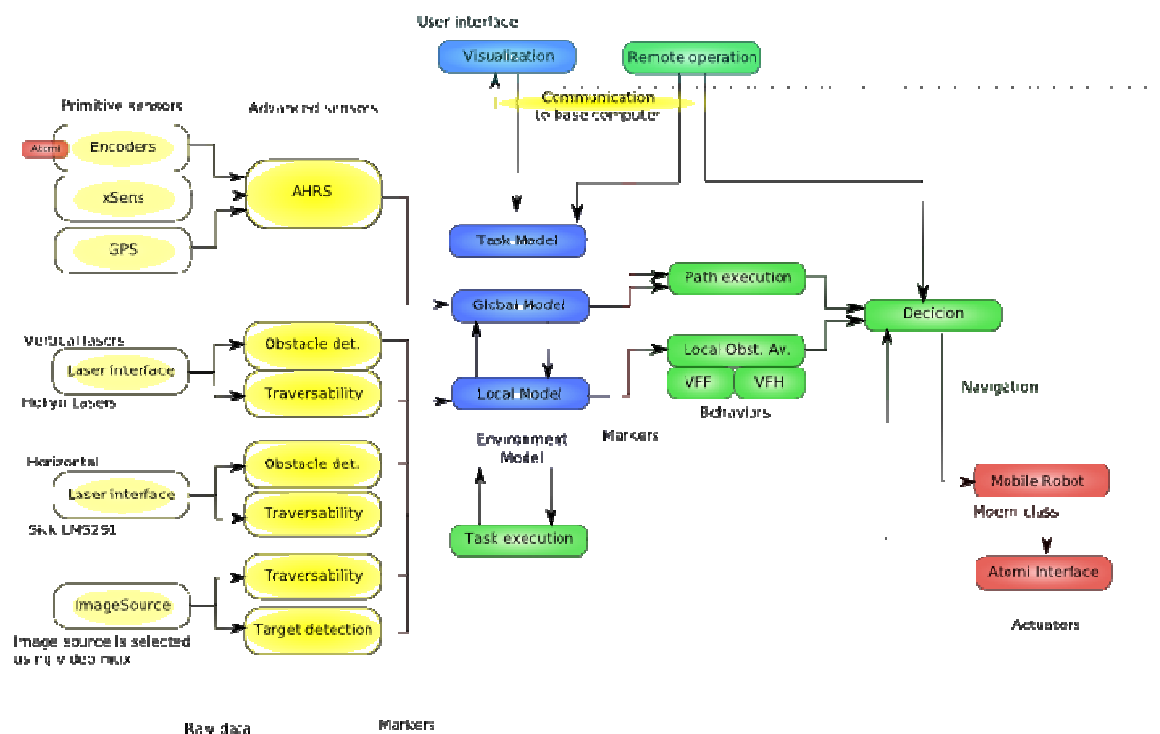


Figure 3. Software architecture of Mörri robot

2.2 Localization

Our Robot's position estimation is a combination of information from multiple sensors. GPS receiver's position information is the most important, but alone it is not accurate enough. In normal operating conditions robots position information is a result from extended Kalman filter based sensor fusion process. During GPS outages robot relies on dead reckoning. EKF is used for fusing dead reckoning and GPS information. Robots dead reckoning system consists of motor controller odometer and orientation information got from the xSens Attitude and Heading Reference System module called MTi. In parallel, a new version of MTi sensors, MTi-G including orientation sensors and GPS is used.

Orientation provided by the xSens module is a result of sensor fusion done inside the module. MTi module has 3 MEMS gyroscopes, 3 linear acceleration meters and a 3D magnetometer. The accuracy of the module according to the specifications is <0.5 degrees and <1 degrees for direction of earth magnetic field. The GPS sensor selected for the robot is GlobalSat BU-353. It is based on a SiRF Star III chip and has a sensitivity of -159 dBm. The chip supports WAAS/EGNOS corrections for greater accuracy.

2.3 Sensing

Mörri is equipped with several sensors. It includes several sensors that provide obstacle information for autonomous driving. Main sensor for steering is a Sick LMS100 2D laser scanner that is mounted horizontally to the front of the robot. It can measure 180 degrees field of view up to about 40 meters. This laser measures frontal area of the robot and roughness of the terrain detect traversability of frontal area.

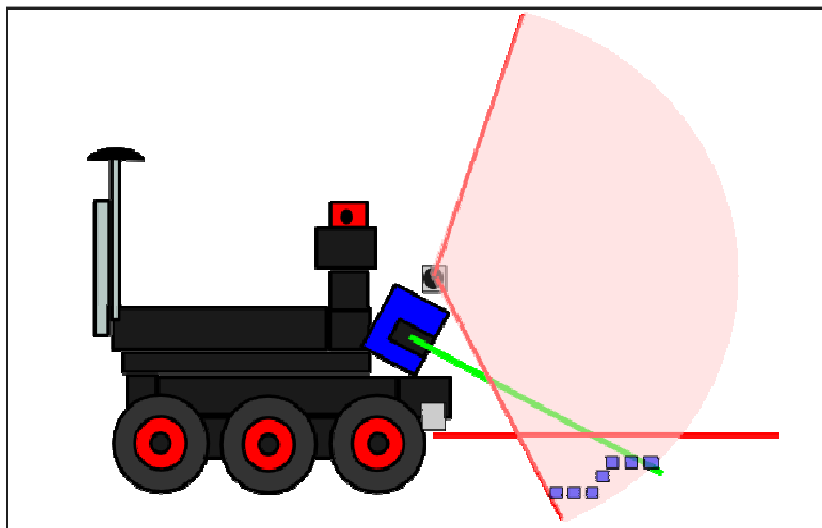


Figure 4. Field of views of robot's lasers

In addition, two Hokyo 2D lasers are used vertically to measure profiles of obstacles in front of the robot. These small size lasers can measure up to 4 meters with 0.5 degrees resolution and they

can be turned (panned) using servo motors. Optionally, a Sick laser can be turned vertically, providing 3d scan of frontal area of the robot, but during movements, it is fixed on horizontal angle.

In previous version [3] the robot was equipped with Pan-Tilt head, where several sensors were mounted, including stereo vision, thermal camera. On autonomous patrolling mode, remote operator can “look around” by turning pan-tilt unit while robot drives autonomously. All instruments placed on head were weather protected.

In current Mörrri, PTU and stereo cameras are replaced with a Ladybug2 spherical vision camera. The camera includes 6 separate cameras that provide full view around the robot 15-30 frames per second. This camera is used for detecting ERI-cards and estimating traversability of surrounding terrain.

As shown on Figure 2, each sensor output is processed and detected targets are represented as markers. These markers are represented on local coordinate system model, and used as input for obstacle avoidance and route reasoning.

2.3.1 Machine Vision

Mörrri is equipped with several cameras. For target recognition, several machine vision methods are used. The machine vision is running onboard and it is used to detect traversable area and calculate visually the movement of the robots. Using Ladybug2 camera, 3D points with color of surrounding can be measured and mapped to be used by human operator. Basically two vision processes are running parallel, one for finding ERI-Cards automatically from scene and one for estimating traversability of surrounding terrain. Orange cards are first detected using plain color filtering and detected sub-images are studied using texture detection. For traversability estimation, similar processing is used, where terrain type is classified basically on grassland, asphalt and sandy pathways. This gives a raw estimation of surrounding terrestrial that provides additional information for robot’s local path planning. As this method is still on early stage and has rather unreliable, it has only small weight on the robot’s environment model and obstacle avoidance.

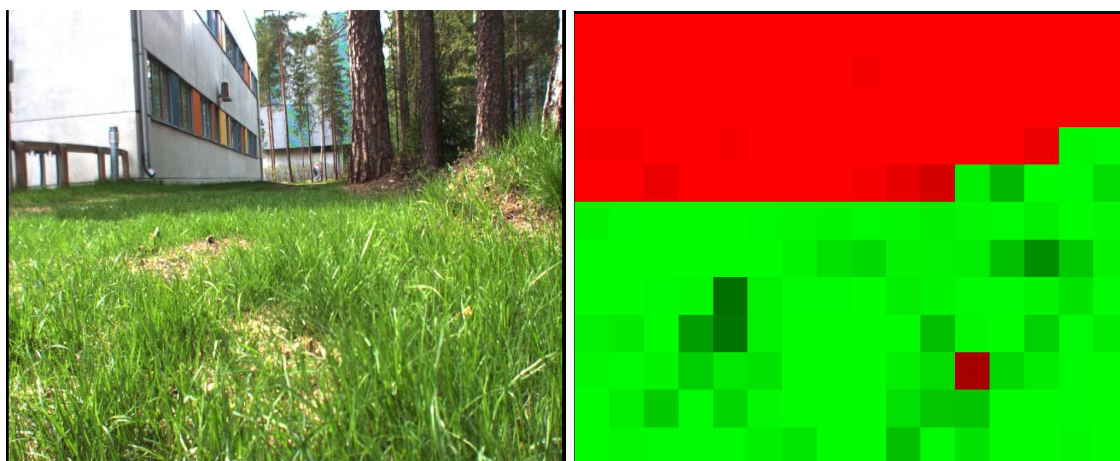


Figure 5. The detection and visualization of traversable area

2.4 Vehicle Control

Robot is controlled using differential steering. Both sides of the robot has its own brushless dc motor, driver electronic and one control electronic that uses both motors and communicate to Robot's main computer.

The robots autonomous waypoint navigation is based on "Follow the Carrot"-algorithm. As a start of autonomous operation, a set of coordinates is given to robot control software. These coordinates are chosen so that between waypoints there are no known obstacles. If an unknown obstacle is encountered, Virtual Force Histogram method [4] is activated in order to avoid the obstacle. 2D and 3D laser scanner data is used as an input for the VFH-method. All obstacles, detected by different sensors and algorithms (like clustering lasers scan points or obstacles detected with vision), are represented as markers and used by VFH. The output markers of each detection algorithms are weighted according their reliability.

Markers are virtual objects that are used to represent robots knowledge of surrounding environment. Markers are calculated from output of different sensors, by clustering scans, or using various machine vision algorithms. They provide good solution for integrating sensors of the robot and represent the world. In addition to markers related to physical world objects, markers can be created related to task execution like route positions where to move, area boundaries as virtual obstacles, or representing unknown area to be explored.

When robot is not in an autonomous mode, direct driving (speed and steering) commands are received from the remote operator. The lower level control boards includes also a watchdog functionality that automatically stops the robot if no commands have received in a constant period, i.e. in case of communication failure.

During operation, robot sends its current state information, which includes location, orientation, head orientation information, and various sensor output or marker information depending on speed of the return channel available. In control station, these are visualized to user.

2.4.1 Visualization and remote operation

As a part of the remote operation unit, a 3D visualization system for collected information has been developed. Visualization software has parallel plug-in threads that process raw information by combining voxels to polygons. Visualization is used two ways; for showing local sensor data (of the robot) like laser scanning and mapped camera pixels, and for showing robots route, current location and locations of detected targets. Further, visualization can be used for drawing new route for the robot.



Figure 6. Visualization of 3D scan

The robot's current location, traveled path, and points of interests are visualized using Google Earth program (www.googleearth.com). Location is updated in real-time, once in a second. Google Earth's polygon drawing tool is used for drawing new routes to the robot. After a new route is saved as KML file, a Python program uploads it to the robot and the robot starts to execute it. Google Earth is used also for reporting the robot's task execution. When the robot takes pictures of interesting targets, it creates an image placemark to Google Earth and user can watch images there. Communication wrapper between Google Earth and the robot's remote operation software has been coded with Python providing Property Service, and using sockets and GE API with "ctypes" python extension



Figure 7: Route map and marker location visualization

2.5 System Tests and safety mechanisms

2.5.1 System tests

The robot's reliability has been tested after M-Elrob in many cases, including ESA Lunar Robot Challenge competition, and several improvements to simplify the system have been made.

Strength: To test the system's power capabilities, the pulling power of the base was tested. The robot succeeds to pull up to 1700kg payload (VW Transporter van) with only about 1/4 of maximum power. [10]

Weather conditions: Several tests have been driven in bad weather conditions. Robot has been operating in rain. In snow (air temperature -10 deg), the whole system worked without freezing one hour.

Communication link: Up to 0.5 km in line of sight was used on driving the robot. The major advantage of radio modem and analog video link is a very short delay that eases the operation in tight places.

Path following: Using previously explained estimators, the robot is capable of driving roads and path ways of given path. The path can be recorded by a human by walking with GPS, or it can be drawn using Google Earth path tool. Previously traveled routes are stored by the robot, and can be recovered and looped continuously by the robot. If better GPS positioning would be available (like using DGPS) human location following could also be developed.

Obstacle detection and avoidance: Using horizontal and vertical lasers, and cameras, many kind of common obstacle on path were detected and avoided. Using scanning vertical lasers, pavements, fences and vegetation were found. However, transparent (such as windows or class door) are hard to find.

Real world conditions: One major problem of using lasers or cameras is the presence of direct sun light. If direct light hits the laser's detection chip, it freezes the whole operation and it must be manually restarted. Also a direct light disturbs the operation of cameras. We have attached shades over the lasers and cameras. However, additional sensors technologies, like microwave radars should be included to the robot to be able to operate in direct sunlight.

2.5.2 Safety

The robot has several safety mechanisms. The lower level electronic has a keep-alive functionality. If no communication from serial port appears in defined time (100ms), the robots movement is halted. The robot is equipped with two emergency stop switches, which interrupt the motor powers immediately. In software level control, collision avoidance is included and active both in autonomous and remote operated modes. It uses 2D laser scanners and bumper to prevent collisions. The robot has also simple (start/stop) remote controller to stop the movement.

References

- [1] Tikanmäki A., Röning J. 2007, Property Service Architecture to robots and resources on distributed system ICINCO 2007, 9.-12. May, Angers, France
- [2] Tikanmäki A., Mäkelä T., Pietikäinen A., Särkkä S., Seppänen S., & Röning J. (2007) Multi-Robot System for Exploration in an Outdoor Environment, IASTED 2007 - Robotics and Applications and Telematics, 29.-31.Aug. 2007 Würzburg, Germany
- [3] Tikanmäki A., Röning J. (2009) Development of Mörri, a high performance and modular outdoor robot, ICRA 2009, 12.-17.5.2009, Kobe, Japan
- [4] Borenstein, J. and Koren, Y., (1991) The Vector Field Histogram -- Fast Obstacle-Avoidance for Mobile Robots. IEEE Journal of Robotics and Automation, Vol. 7, No. 3. pp. 278-288.
- [5] Mörri pulling VW transporter http://www.youtube.com/watch?v=FwYSzQM5D_Y