Robot RUDA - Introduction and Current Research

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***Abstract*—**This paper aims at a robot RUDA designed for detection of survivors in debris and avalanches. After a brief introduction of the robot itself there is the current research of the robot localization in a large outdoor environment described. In the second part there are optional sensor modules described. Available modules mentioned in the paper are a manipulator, bioradar, avalanche transceiver and LIDAR/stereocamera module.

***Keywords*—**Rescue robot, Teleoperated, Bioradar, Thermocamera, Navigation

I. Introduction

Use of robots in search and rescue missions is more and more popular. The reason for this is quite simple - robots can enter dangerous areas inaccessible for people, operate tireless and, in many cases, more efficiently. As the robots get more sophisticated, they can handle more difficult tasks like remote or autonomous exploration of dangerous places. In case the robot was damaged, it would be possible to repair even if it was totally destroyed and, besides, it is better to loose a robot than a human.

In this paper there is a rescue robot RUDA presented with a focus on description of localization of the robot in large open areas with few obstacles and various sensors that the robot is able to carry. RUDA is being developed at our university as a multipurpose robot suitable for various tasks. Based on the task, it can be equipped by a specific module carrying a manipulator, bioradar, avalanche transceiver, camera system with a LIDAR/stereocamera combination and many more. RUDA has a protective painting so it can be easily decontaminated and thus it is suitable even for various army, firefighting, pyrotechnic or rescue operation.

RUDA is a middle sized tracked vehicle (fig. 1) designed to be able to maneuver both indoors and outdoors. Its track chassis can overcome some terrain obstacles, but is small enough to go through a common door, at the same time. The robot weighs about 150kg and its outside dimensions are approximately 98x140x70cm. Weight and size vary according to the installed additional modules.

Fig. 1 Photo of the RUDA robot.

II. Localization of the robot in an indoor environment

Indoor localization is utilized when the robot operates inside buildings. It relies mostly on the flat ground and walls. If the building is significantly damaged and its walls and ground can not

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be recognized the robot needs to rely on stereocamera with worse precision.

While working with maps the robot controller is able to operate in two modes: SLAM mode and localization mode. SLAM mode enables robot to build a map of unknown environment and localize itself in this map. Localization mode is used when there is a map of the environment available (usually from the prior SLAM walk through) and the robot needs to localize itself in the map according to its sensor observations.

In mapping and localization tasks we intensively use particle filter based algorithms as they are non-parametric, rather universal and with a decent performance. For indoor SLAM mode we use an existing implementation of the Rao-Blackwellized particle filter SLAM available in ROS called Gmapping [1]. The SLAM process obtains data from the odometry, scans from plane laser scanner (LIDAR usually) and constructs the map according to these data.

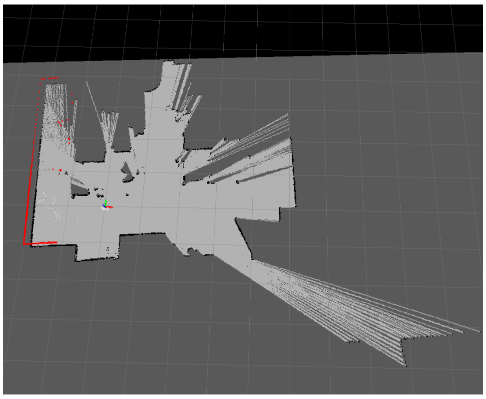

Fig. 2 Map generated by gmapping SLAM.

Localization in the given map uses an adaptive Monte Carlo localization algorithm [2]. The algorithm is based on a universal particle filter algorithm as described in [3]. Each particle represents particular pose of the robot. Enhancement of the universal particle filter algorithm is an adaptive change of amount of particles placed in the environment according to the density of the particles in the state space. We use an existing implementation from ROS called AMCL that uses the Augmented MCL and KLD-MCL algorithms [4].

III. Localization of the robot in a large outdoor environment

As a part of the navigation system of RUDA we are working on a solution of localization of the robot in a large outdoor environment. There is a reliable solution of localization based on a GNSS like GPS, GLONASS or GALILEO. Unfortunately, in some cases, this approach can't be used due to the missing or noisy signal from the satellites. In such cases we have to rely on the sensors of the robot itself.

For the areas with a high density of interesting objects (textures, 3D objects or artificial markers) we can use existing SLAM methods based on 3D LIDAR, stereocamera or some sensor sensitive to the markers. In case the robot operates in an environment with a flat terrain and a very few interesting objects common SLAM approaches fail due to the limited range of sensors. For this purpose we are developing solution of localization based on set of cameras, odometry information and a long-range laser rangefinder.

IV. Principle of the long-range localization

Our approach is based on a FastSLAM algorithm. The main difference is the way of obtaining of observations. In our solution the observation is obtained in two phases. In the first phase interesting objects are detected in the surroundings of the robot. In the second phase the rangefinder is used to obtain an observation in a particular direction. Object detection and obtaining of the observation are independent tasks that can be solved using several approaches.

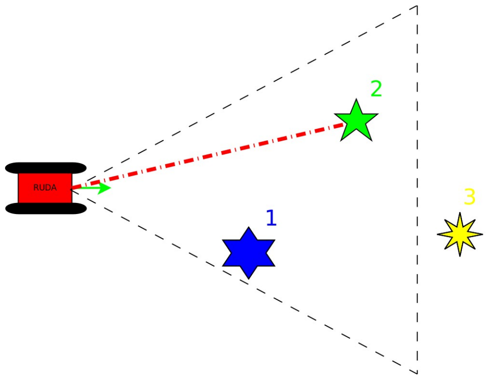

Fig. 3 **Principle of long-range localization.**

V. CONSIDERED ENVIRONMENT FOR THE LOCALIZATION

As mentioned before there are some assumptions about the environment in which the long-range localization works. It is designed for an environment with only a few of detectable objects. The objects have to be detectable by both camera and laser rangefinder. These requirements satisfy solid objects of a significant volume and texture distinguishable from the surroundings. In the environment there can be only a few objects. The localization approach could, in theory, work also in the environments with a high object density but its performance would be probably worse compared to the existing approaches like ICP library for 3D laser SLAM [5] or RDBG SLAM[6].

Fig. 4 **Example of environment considered for long-range localization.**

VI. CONSIDERED ENVIRONMENT FOR THE LOCALIZATION

A map for the outdoor localization can be represented in several ways. Considered ways for mostly flat terrain with only a few objects were an occupancy grid [3] and vector representation. The occupancy grid is a grid of cells. Each cell of the grid carries a value of probability that it is occupied by an obstacle. Free space has a small probability of being occupied and obstacles are covered by the cells with a high probability of occupancy. Advantage of the occupancy grid is that it represents the map in a simple deterministic way with constant time complexity of map updates. The occupancy grid with reasonable resolution is inconvenient for large areas due to the quadratic growth of the number of cells with radius of the area.

In a sparse environment the problem with memory used by the occupancy grid can be solved using compression methods. One of them is a tree compression [7] in case the map is represented by a tree of cells. Each level of the tree represents cells with a particular size. If the whole cell is empty or occupied it contains value of probability directly but if the cell is occupied partially it has a subtree of smaller cells describing the occupancy more in detail. This applies on the tree nodes up to given minimum cell size. The compression is visualized in Fig. 5.

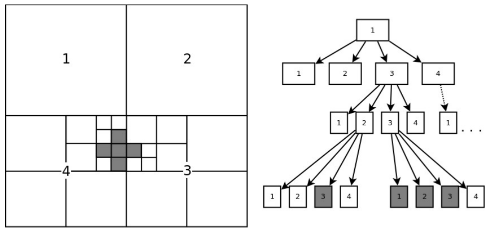

Fig. 5 **Tree compression of occupancy grid.**

Another drawback of the occupancy grid is that it has no implicit semantics of the objects it represents. Basically the occupancy grid has no information about relationship amongst occupied cells and object they represent. Since we need to connect an additional information with an object in the map we decided to use a vector approach of the map representation.

In our approach each object is represented by a Gaussian Mixture Model (GMM). This gives us two important advantages: we can compress the map data and we also have information about particular objects in the map so we can connect additional information to it. It is good to mention that this approach can be effective only for the sparse maps. Each object is described by a set of weighted multidimensional Gaussians (1).

An object in the map is represented by a particular GMM. This way the object can be addressed. Addressing of the object in the map allows us to connect additional information to it: informations for optical recognition of given object and also set of distance vectors obtained by the rangefinder. Set of prior observations of given object are used for the GMM adaptation when new observations of the given object appear.

When a new observation appears it is necessary to connect it with the particular object. If a match probability of given observation overcomes defined threshold it is connected with the object with the highest math probability. If the observation does not overcome the threshold a new object is created.

$$P(x)=\prod_i \omega_i \left(\frac{1}{\sqrt{|\Sigma_i| 2\pi}} e^{\frac{-1}{2}(x-\mu_i)'\Sigma(x-\mu_i)} \right) \quad (1)$$

For adapting of the Gaussian mixture models we use a Maximum Likelihood algorithm [8]. The idea of the ML algorithm is to maximize probability of the matching training vectors of the given class to the Gaussian mixture model.

Process of the map update is described in the detail by the algorithm 1. Input of the algorithm is a map *M* that is a set of GMMs - each of them describes one particular object, set of map object observation *MO* which contains sets of observations of each object in the map, a new observation ***o*** and a threshold *T* that defines minimum match probability for the observation belonging to the particular object.

Data: M_t ,**o**, M O_t , T
Result: M_{t+1}, M O_{t+1}

Pa = CameraMatch(M_t , **o**)
C = arg max (**Pa**$_i$ M_t[i](**o**))

$0<i\leq|M_t|$

$Pp_C = Pa_C\, M_t[C](\mathbf{o})$
if $Pp_C \geq T$ **then**
  $MO_{t+1} = MO_t$
  $MO_{t+1}[C] = MO_t[C] \cup \mathbf{o}$
  $M_{t+1} = M_t$
  $M_{t+1}[C] = TrainGMM(MO_{t+1}[C])$
else
  $O_{new} = \{\mathbf{o}\}$
  for (j = 0; j < M in Observations; j++) **do**
    $\mathbf{o_j} = GenerateObservation(\mathbf{o})$
    $O_{new} = O_{new} \cup \{\mathbf{o_j}\}$
  end
  $MO_{t+1} = MO_t \cup \{O_{new}\}$
  $M_{t+1} = M_t \cup \{TrainGMM(O_{new})\}$
end

Algorithm 1: Map update

VII. Laser aiming

Another part of the problem is choice of the best objects for obtaining observation from the laser rangefinder. At the moment the n closest obstacles are chosen, but this approach has several pitfalls. Quality and usability of the observations is affected by distance to the object, properties of the surface of the given object and also by the position of the object and its relation to other objects. Improvement in the object selection is essential for the precision of the localization.

VIII. Sensor modules

The hull of the robot can carry various sensors as was mentioned in the Introduction. Currently, the modules include a Manipulator, Bioradar, Avalanche transceiver and LIDAR/stereocamera module.

I Manipulator

Manipulator module adds a three degrees of freedom manipulator with a two-finger gripper. It can be mounted to the rear module socket on robot hull. The manipulator can carry up to 2kg of payload and it is equipped by an additional camera with thermovision. It helps the operator to recognize living people under debris in cases when the person is not visible by a normal camera. Operator of the robot can switch between the normal camera and thermocamera to see the scene in both modes.

II Bioradar

Since RUDA has been designed for help with search of human beings in various situations, it has been set with sensors for such tasks. One of the most important sensor to achieve this is a bioradar. Bioradar is a device used for bioradiolocation [9], which is a method for remote detection of various biological objects by means of radar [10].

The idea of human body detection by radio waves is based on detection of modulation of continuous radio signal in time caused by typical movements of the human body and internal organs [11]. Movement of the body can be caused by conscious movements (mainly movements of extremities) or unconscious movements (movements of organs). From the human body detection point of view, we aim at subconscious movements because, most likely, the affected person is unconscious.

Organs causing detectable movements are heart and lungs. These organs generate periodic subconscious (automatic) movements of different frequency and amplitude. Heart beating (cardiac movements) causes motion with an amplitude measured in millimeters at frequency ranging from

0.7 Hz to 2.5 Hz [12]. Breathing (respiratory movements), on the other hand, causes motion with the amplitude 3 orders of magnitude greater than those of heart beats at frequency from 0.2 Hz to 0.7 Hz [12]. Hence, detection of breathing is the most viable option for RUDA as its amplitude is much greater than of the other subconscious movements.

Bioradars are usually used in situations where we need to detect persons behind obstacles. It has been successfully used in war missions, police operations or even on various disaster sites. There are various ready-to-use devices available on the market, but none of them was usable for our robot. To be able to use this technology we cooperated with a Czech company RETIA who helped us to modify their ReTWis [13] radar to fulfill our expectations and needs. The radar is originally designed to detect movement of people, but it is able to measure even the micro-movements such as breathing. One of the most important aspect of the successful measurement is frequency and positioning of the antenna [14], placement of which we remotely control by 2 DOF manipulator. Precise alignment with the obstacle is achieved by feedback from infrared distance meters and tactile sensors. The final version of the modified device mounted on RUDA is in action in the Figure 6.

Whereas the bioradar is well known technology for living person detection behind obstacles, we were thinking about different approaches to detection of dead people, too. People who might be dead do not provide movement to be detected by the bioradar. One of the possible solutions to detect them is use of georadar (GPR -- Grounding Penetrating Radar), which is a device using pulses of ultra-wide band of radio waves instead of continuous waves (as in the case of bioradar). There is a wide range of frequencies used in georadars each of them penetrating various materials to different depths (e.g. 25 MHz pulses being used for geologic profiling are able to penetrate ground up to 57 m deep, 200 MHz waves go down to 28 m [15], whereas the modern systems operating at 1.6 GHz are being used for analysis of structural concrete, roadways or bridge decks and can penetrate the material up to 0.3 m [16], whereas in bioradars the typically frequencies are orders of GHz). The main advantage over the bioradar would be the possibility to search in higher depths and even for dead bodies, which would allow for more thorough survey of the disaster site. Use of such device originally designed for a geological inspection in disaster site inspection scenario has not been tested, yet. We are working on experiments aiming at either confirmation or disapproval of this idea.

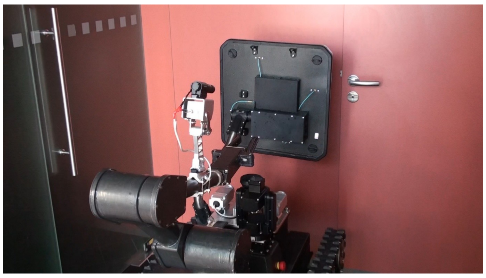

Fig. 6 **Photo of bioradar sensor mounted on robot in action.**

III Avalanche transceiver

The avalanche transceiver module is a simple module based on a stock avalanche transceiver, which is able either to receive or send signal. The avalanche transceiver was extended by an additional communication interface that allows user to read state of the avalanche transceiver. The device is always switched to the receiver mode so it searches for a signal from other avalanche transceivers that implicitly broadcast radio signal. The transceiver estimates direction and distance of the broadcast signal from the transceiver. It allows the robot to navigate closer to the person under avalanche. Of course avalanche transceiver requires the person to wear other transceiver. This is a limiting factor but usually people, who go to an avalanche field, carry an avalanche transceiver.

IV LIDAR/stereocamera module

The LIDAR/stereocamera module is a module equipped with two cameras, which work in pair together as a stereocamera, and a LIDAR (plane laser rangefinder) made by SICK company. This module has a

driver connected to a HAL (Hardware Abstraction Layer) that uses robot main computer to compute disparity from the stereocamera images. The LIDAR has a driver that only change format of data for higher layers of control system. The LIDAR/stereocamera module can be installed on the front socket on robot hull - it can be installed on top of the bioradar module, too. During usage of the bioradar is this sensor covered by an antenna of the bioradar, which makes the data from cameras and LIDAR invalid. Fortunately, the robot is not allowed to place the antenna of the bioradar while it is moving so this is not limiting - RUDA has to home the bioradar manipulator, activate the LIDAR and stereocamera and then it can move according to the sensors again.

IX. Conclusion

At the moment RUDA is a working prototype. It can be used in real missions but there is still development going on. It has been tested in a testing polygon but not in any real missions, yet. The robot was also awarded by a gold medal on an International Engineering Fair (MSV2015) [17].

Currently the most effort is devoted to the localization system of the robot. It is essential for autonomous operation of the robot and it is also an important supportive system in the remote-controlled mode of operation. Next step will be a fusion of the localization approaches to provide reasonable localization information across various environments. With a robust localization the autonomous behavior of the robot can be significantly extended.

To conclude, RUDA has still space for improvements and further development but in its current state it is an interesting solution for rescue teams in various mission types. Potential of the robot will grow with improvements of the autonomous control and also with additional sensor and effector modules.

Acknowledgment

This work was supported by the Ministry of Education, Youth and Sports of the Czech Republic from the National Programme of Sustainability (NPU II); project IT4Innovations excellence in science - LQ1602 and Secure and Reliable Computer Systems FIT-S-17-4014.

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