# RUDA - Robot for Search for Human Beings in Debrits and Avalanches

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***Abstract*—The paper concerns about prototype of robot aimed on detection and rescue of people in debrits and avalanches. As first the robot is introduced as a chasis that can be extended with modules. Currently available modules are described later in the paper. Finally paper decribes possible use cases and missions for the robot a discusses future improvements and further development of the robot.**

***Keywords*-robot, rescue of people, bioradar, debrits, avalanche**

## I. Introduction

In todays worl robots are still more and more common part of human lifes. We use robots for manufacturing, cleaning, in military operations and many other fields of human activity. Advantage of robots is that they can work with high precision and they do not need to rest. Another advantage is that in case robot gets damaged or destroyed there is no life lost - only material. Protection of health and lifes is probably the main reason to use robots in rescue operations. Robots can operate in dangerous areas that are too risky to be entered by humans. Robots can easily cary additional sensors and tools that are too large and heavy for human or that require precise positioning. Disadvantage of robots is that they have limited motion capabilities - they usually use track or wheel propulsion that has many limitations. Still usage of robots brings many benefits for rescue teams.

Using robots for dangerous missions is not a new idea. There are several teams in the world that develop robots for this kind of missions - for example robotic system called Orpheus [1] that is already used by chemical division of Czech Army during their missions, tEODor Robot developed by Telerob company [2] used by pyrotechnists or MOIRA2 robot [3] - the successor of inspection robot MOIRA. This paper describes project of universal robot aimed on rescue missions called RUDA. The RUDA is more similar to Orpheus or MOIRA robots - it is aimed on sensors more than effectors especially compared to tEODor robot that is equipped with a set of tools usable for removing layers of material and dismantling bombs. The main difference between RUDA, MOIRA and Orpheus is in used sensors. Orpheus is aimed on chemical pollution, MOIRA on remote inspection. RUDA has a set of sensors aimed on searching for people. Combination of sensors that RUDA carry is probably unique in world of rescue robots.

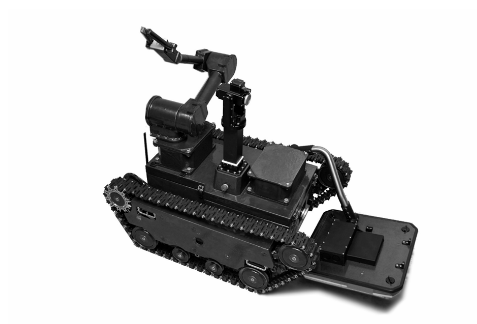

Figure 1. Photo of the RUDA robot.

## II. RUDA - Robot for Search of Human Beings in Debris and Avalanches

The robot called with acronym RUDA is being developed at Brno University of Technology at Faculty of Information Technology. The development team compounds mostly of students and their supervisors. The leader of the team is doc. Ing. Martin Drahanský PhD.

RUDA is a robot aimed on rescue of people in debrits, avalanches and generally in dangerous situations. Its capabilities are limited compared to human but it can operate in environments that can not be entered by human. Example of such environments is avalanche field where is hight probability of avalanche landslide or environmend contamined by dangerous chemicals.

The robot is primarily aimed on detection of people in dangerous environments. Secondary it can help those people to get out from imminent danger. The robot can move around the operation area on tracks. The tracks are driven by two independent electro-motors powered from internal battery. Normally the robot is remote controlled. It communicates with operator via cable or via wireless data transfer. With cable connected the robot is also connected to source of power so it has theoretically unlimited operation time.

To provide good overview of surrounding situation the robot is equipped with two fixed cameras - front and rear. Moreover it has PTZ camera intalled on prismatic banister.

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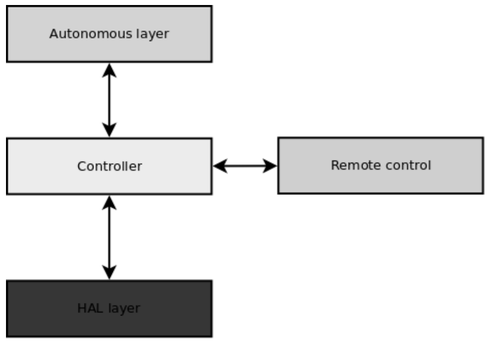


Figure 2. Layers of control architecture.

The banister can can be rised for aproximately 20 cm so operator can see surrounding terrain and all nearby obstacles. During remote controlled operation an operator can control robot tracks by joystick and receives visual feedback from cameras. The robot can be extended by several modules that bring additional sensors and effector in form of manipulator. All the modules are optional and robot can operate without them however some sensors are necessary for autonomous mode of robot (described later).

Internally robot uses hierarchical architecture as described in figure 2. Basic control loops are maanged by simple fast modules. High-level and more complex tasks are implemented as proceses on universal main computer with operating system and high level of abstraction from hardware. Software on the main computer can compounds of three layers: a HAL layer, a controller layer and an autonomous layer. The HAL layer is responsible for low-level communication with hardware control modules and other hardware. The HAL provides abstraction from aprticular buses and low-levep protocols for alyers above it. Robot hardware is interconnected with the main computer via CAN bus, RS-232 bus or via ethernet. HAL provides single entrypoint with unified interface for communication with particular hardware components.

The controller is a layer above HAL thas is responsible for transfer and convertion of control commands and feedback data. Controller is also responsible for communication with operator. Last but not least the controller implements control logic of the robot. It is responsible for avoiding run of conflicting tasks, for command prioritization and for interconnection of fast low-level control loops to get overall information about state and condition of the robot.

## III. Available modules

The described in previous section is intended as a platform that can be extended with extension modules. Extention modules bring additional sensing and action capabilites for the robot. Currently modules include Manipulator, Bioradar, Avelanche finder and Sensor module.

### A. *Manipulator*

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

Manipulator can be controlled with two approaches: with controlling of particular joints and with endpoint possition control. In thje first case each joint of the manipulator is completely controlled by operator. This mode is usable in cases when operator needs very precise control of the manipulator. In the second case the manipulator is controlled by setting endpoint position. Movement of the manipulator is computed, planned and executed by robot computer. This mode is easier to learn for the operator and more convenient. Disadvantage is that the manipulator does not see obstacles around itself so it can not be used in cases when manipulator needs to avoid obstacles while moving. Of course operator can switch between those two modes instantly. Gripper of the manipulator is controlled separately - controll of the gripper is the same for both modes of the manipulator.

Manipulator is equipped with two BLDC motors in shoulder and elbow joints and with one DC motor that rotates its base. The BLDC motors are controlled by dedicated hardware controllers that implement BLDC motor control algorithms [4]. The DC motor in manipulator base is controlled by manipulator HAL directly. HAL interface for the manipulator allows higher control layer to control manipulator movements with necessary safeguards (motor overload, hard joint limits) and provides those layers encoder data. The high-level control layer manages trajectory planning and collision avoidance during manipulator movements. The high-level control of the manipulator is based on OpenRAVE [5]. It works with manipulator and robot hull kinematics model so it can prevent collisions of manipulator with robot hull or collisions of manipulator with itself. For trajecotry planning the manipulator uses RRT algorithm [6] and for computation of inverse kinematics it uses analytic IKFast solver implemented in OpenRAVE. Model of the manipulator can be observed on figure 3;

### B. *Bioradar*

Bioradar is a device that can detect living beings behind solid obstacles. It uses a micro Doppler effect to detect micro motion of human body like breathing or heartbeat [7]. It sends short sine wave pulses and receives reflected signal. It the transmitted pulse meets moving obstacle like human chest during breathing or human heart it slightly changes its frequency. According this small change the bioradar device can detect living person behind obstacle. The bioradar we

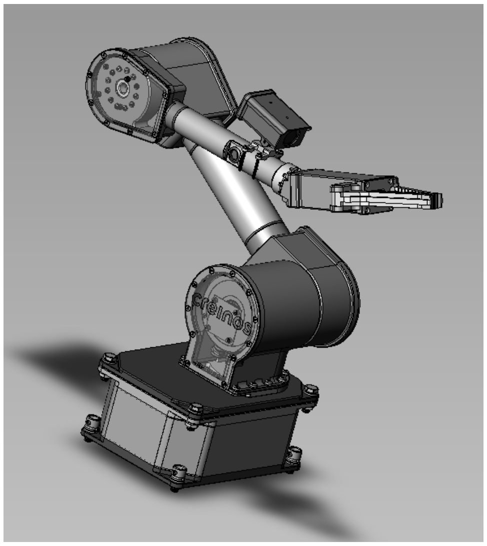

Figure 3. Manipulator CAD model.

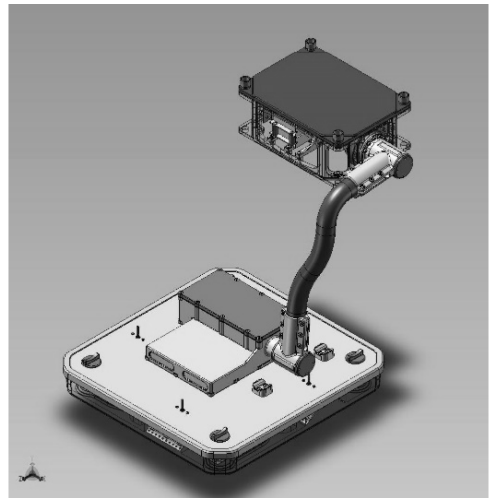

Figure 4. Bioradar CAD model.

use on a robot uses UWB (ultra wide band) signal in a large part of a spectrum to better overcome obstacles that attenuate signal on particular frequency [8]. Unfortunately the bioradar has several limitations. First of all it can detect only people with signs of life. If person does not breath and his/her heart does not beat than hte person can not be detected by bioradar. Other problem is that the bioradar signal is intensively attenuated by metal. Many buildings use steel fittings in concrete constructions so some debrits significantly decrease operational range of the bioradar. And lsat but not least the bioradar is tuned to reflect transmitted signal from human bodies that have similar properties as water so the bioradar does not work in cases the person is under water or snow avalanche. Still the bioradar is very usefull sensor for finding victims under debrits or for finding hostile people hiding behind walls.

For use on RUDA robot the bioradar was integrated into bioradar module that can be observed on figue 4. The bioradar antena can po positioned by manipulator with two degrees of freedom. It can be placed on the floor or on the wall. For better placing the antena is equipped with four ultrasonic distance sensors that navigate the manipulator to place the andena as close as possible to the solid surface without colliding with it. These sensor allow robot to place the manipulator autonomously. This is used in autonomous mode described in chapter Autonomous Mode. The bioradar we used is a product of RETIA company. It was modified and integrated into bioradar module by our team.

The bioradar provides information about direction and distance of detected person in 3D space. Still output of the bioradar is difficult to interpret by machine due to false positives and uncertainity in its output. The bioradar output is displayed to the operator so operator can determine whether the person was detected or not. Automatic processing of bioradar output is a subject of further research.

### C. Avalanche finder

The avalanche finder module is a simple module based on avalanche finder as shown on figure 5. The avalanache finder was extented with additional communication interface that allows HAL to read state of avalanche finder. The finder is always turned into receiver mode so it searches for signal from otehr avalanche finders that implicitly broadcast radio signal. The finder estimates direction and distance of broadcasted signal from receiver. It allows the robot to navigate closer to person under avalanche. Of cource avalanche finder requires the person to wear other finder. This is a limiting factor but usually if people go to avalanche field they usually cary avalanche finders.

The avalanche finder module can be mounted on rear socket of the robot. The finder itself is as far from robot motors as possible to avoid interference with motor electromagnetic field. From point of view of the operater the avalanche finder interface shows active detections and direction and estimated distance to detected signals. Output data from the finder are also used in autonomous modes when robot automatically searches area.

### D. Sensor module

Sensor module is a module equipped with two cameras that work together as a stereocamera and LIDAR (a line laser rangefinder) made by SICK co [REF SICK LIDAR]. This module has a driver connected to HAL that uses robots main computer to compute disparity for stereocamera. The LIDAR has a driver that only change format of data for higher layers of control system. The sensor module can be installed on front socket on robot hull - it can be installed on top of bioradar module too. A CAD drawing of the module


Figure 5. Foto of avalanche finder used on the RUDA robot.

can be observed in figure 6. During usage of bioradar the sensor module is covered by bioradar antena so data from sensors has to be ignored. Fortunatelly hte robot can not place bioradar antena while moving so it is not limiting - robot has to home bioradar manipulator, activate sensor module and than it can move according to sensors again.

The module is essential for semi-autonomous and autonomous operation of the robot. Laser scans are used for construction of map of surrounding environment. This map allows robot to navigate autonomously to given target. The flat scan from laser is usually used in indoor environment. The stereocamera pointcloud on the other hand is usefull in outdoor environment where it helps the robot to get rid of terrain structure and obstacles. It provides information about obstacles that can not be seen by other sensors usually because they are above ground like tree branches or some hanging objects.

## IV. Autonomous Mode

Despite the robot is primarily intended as remote controlled machine it is equipped with decision making system that allows the robot to work in partially or completely autonomous way. There are two main reasons for autonomous mode. First of them is to offload a part of work with controll of the robot from operator to robot computer. It includes tasks like moving to designated target position, to search selected area with sensor or to avoid collisions and falls during high-level control. The second reason is that autonomous mode halps the robot to recover from situations when signal from operator station is lost. It might happen because of getting too far from operator station, because of new sources of radio noise in area or because of damage of antena. In such cases the robot tries to return back to place where it can receive signal from operator station again.

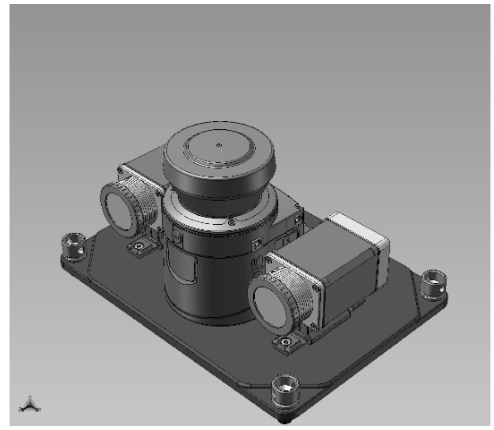

Figure 6. Sensor module CAD model.

The autonomous operation of the robot is based on Robotic Operating System (ROS) [9]. It uses ROS navigation stack for trajectory planning and other parts of ROS for decision making and high-level tasks. The trajectory planning uses a set of algorithms available in OMPL library [10]. Structure of transformation frames used for localization of robot and its parts is shown in figure 7. A graph in the figure does not show any additional modules lika menipulator or bioradar - it only describes the moving base of the robot. The GPS frame called gps is a whole world frame and robot is usually located somewhere in this frame. During local or indoor navigation the GPS frame is not used. The consecutive frame called map is a frame of local map for local navigation. In this map is robot located according to odometry as says the odom_combined frame. Combined means that the odometry information could be a fusion of sevaral sensor including IMU, odometry from the motors and possibly optical odometry based on cameras. Other frames called base_footprint and base_link designate centre of the robot and centre of robot footprint on the floor that is used in 2D localization tasks. Finally from the base_link frame there is a tree of other frames for particalar components of the robot. Of course the transformation tree does not include frames for all the components but it contains only components that are important for sensing, trajectory planning and collision checking.

Essential part of autonomous mode is localization. With proper localization the robot control system can plan trajectories to reach desired destination points. Without proper

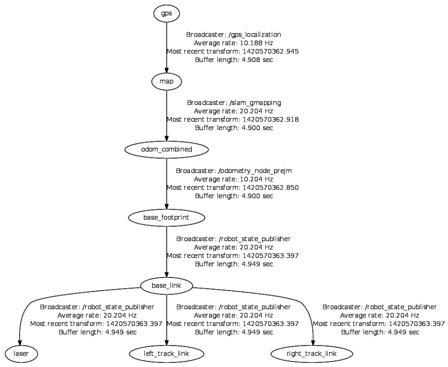


Figure 7. Tree of transformation frames used in robot control based on ROS [9].

localization the robot is limited to naive obstacle avoidance only. The autonomous mode differs for indoor and outdoor localization. The outdoor localization compounds of global and local localization. The gobal localization is based on GPS, the local localization is basend on other sensoprs like ultrasonic rangefinders, cameras and stereocamera. Global localization is used to estimate position of the robot in area map and local localization serves for purposes of obstacle avoidance and trajectory planning.

On the other hand indoor localization is based on LIDAR. LIDAR works in one plane only and has shorter range but it is very precise. The robot uses the Rao-Blackwellized particle filer SLAM algorithm to learn grid maps from laser range implemented in gmapping SLAM [11] that is a part of ROS environment. The SLAM creates map during robot motion. It creates map all the time it operates in indoor environment. In case it needs to localize itself it matches current laser scan to the known map and if it finds a good match, it estimates its location. Of course this method of localization has its limitations. Generally it has problems to estimate proper position of the robot if there is not enought interesting points. The interesting point is a point and its neighbourhood observable by sensor that is unique. Example of such point is a pillar in the corridor or niche for window or open door. Another problem of used SLAM method is that environment might change - for example someone closes the door. Compared to human beings the robot has no experience of steadiness of objects. It can not determine easily which objects can be used as a sources for localization and which can not be used. Fortunatelly the SLAM method is probabilistic which makes it robust to small changes. Still there is space for improvement. One of research project was aimend on developing localization based on interesting points observable by camera. Interesting points observable by camera differ from those observable by LIDAR so this solution could significantly improve robustness of indoor and also outdoor localization.

## V. Missions and Use Cases of The Robot

The RUDA robot was designed to be able to solve various missions in various environments. Mission vary in complexity of solved tasks, in environment and operation conditions and also in posibility of using autonomous behaviour. Robot operation time is limited to cca 30 minutes. This time vary according to modules installed on the robot and usage of those modules and also according to intensity of robot motion. Unfortunately the robot was not tested in real missions - all experiments were conducted in artificial situations in testing polygons or during demonstrations. Still the robot proved itself to be able to solve particular tasks required during real missions so it is supposed to be usable for real missions. The 30 minutes long operation time is sufficient for following missions.

### A. *Searching debrits*

In case of earthquake or accident the building might collapse. The robot can drive through the debrits and search for surviors. It can overcome difficult terrain in debrits and it can use bioradar and thermocamera for searching. In this mode the robot has to be controlled by operator most of the time. Autonomous mode can be used for moving towards the area with debrits. Robot can use manipulator for removing small obstacles and for checking statics of debrits before humans enter the area.

### B. *Searching contamined area*

Robot can operate in areas contamined by dangerous chemical or biological pollution. The hull and most of modules are prepared for chemical decontamination. Robot surface is also heat resistant so the robot can withstand fire for a short period of time. It can use camera, bioradar and thermocamera during search for surviors in this area. In this kind of mission robot can operate in autonomous mode and it can make map of area from covered with data from thermocamera an bioradar. Operater can go through the data after robot finishes the mapping. Unfortunately some parts of the robot including tracks, bioradar antena and LIDAR can not be decontamined so they have to be disposed after mission and replaced by new parts.

### C. *Searching avalanche field*

For operation on snow the robot has to be equipped with wide tracks. Robot can search given area according to GPS autonomously. In autonomous mode the robot can avoid obstacles and report if it detects signal from another avalanche finder. In case of falling into the snow the robot still reports its position so it can be recovered later.

### D. *Removing explosives and other dangerous objects*

Another use case of the robot is manipulation with dangerous or suspicious objects. Suspicios object can be bag left somewhere on public place. It is dangerous for human to approach the bag because it may contain explosives. It is safer to use remote controlled robot to reach the bag, grasp it a move it to the pyrotechnic container or to another safer place. Robot can also manipulate with dangerous chemicals and thanks to good surface protection it can operate in environments that are inacessible for human. Robot is not armored so it can not withstand explosion in its proximity but still sacrifice of robot is less serious than sacrifice of human life.

## VI. Conclusion

The paper brought a brief introduction of project of rescue robot with acronym RUDA. Currently the robot can be used in several use cases. Greatest advantage of the robot is that it can take the risk of operating in dangerous areas so humans can stay in safety. Robot is remote operated however it has limited autonomous capabilities. Unfortunately the robot itself is a prototype that is not used in real missions but the robot was presented to rescue teams from several areas including fire brigade, pyrotechnists or police teams and they were interested in testing this prototype. The robot was also awarded by gold medal on International Engineering Fair (MSV2015) [12].

Despite the robot can be used in real missions there are many things that could be improved. Many of them were sugested after discussion with experts from rescue teams. There is a space for improving robot's chassis to improve transmittance through rough terrain. With additional stabilizating rear wheel the robot could climb up greater terrain gradient . Better dumping would help the robot to overcome difficult terrain where it has to fall from height. This is a common situation when riding over debrits.

Another area of improvements is sensoric system of the robot. We received several suggestions about additional sensor and effectors that robot could be equipped with. The suggested sensor include roentgen scanner that is used in pyrotechnists missions to scan suspicious objects, sensors of chemical pollutions and also sensors for measuring stability of damaged buildings. Other sensor would help the robot to move more smoothly and effectively - for example pressure sensors on gripper fingers or optical-flow sensor for improving odometry.

To conclude the RUDA robot has still space for improvements and further development but in actual state it is an interesting solution for rescue teams in several mission types. Potential of the robot will propably grow with improvement of chassis and autonomous control and laso with additional sensor and effector modules.

## Acknowledgment

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