# Intelligent Robots

## TELEOPERATION AND SEMIAUTONOMY MOVEMENT MODES OF IBIS ROBOT

**Piotr Bigaj, Maciej T. Trojnacki, Jakub Bartoszek**

***Abstract**: The work presented in this study is concerned on a subject of simulation and implementation of teleoperation and semiautonomy modes for IBIS mobile robot. The construction of the robot as well as used sensors have been described. The unique algorithm for semiautonomy mode has been elaborated and depicted here. Software simulation environment based on Matlab/Simulink package with Simulink 3D Animation toolbox and research activity has been presented as well as practical experimental results of proposed method for real, outdoor conditions of IBIS operation.*

***Keywords**: mobile robot, navigation, teleoperation, semiautonomy, computer simulation, experimental research.*

***ACM Classification Keywords**: I.2.9 Robotics - Autonomous vehicles, Operator interfaces, Sensors.*

### Introduction

Autonomous robot movement in unknown environment is one of key issues nowadays for mobile robotics. The problem is already taken up for over two decades amongst different research and developments centers all over the world. The most popular of these includes a task of mobile robot movement from the starting point to a destination point and simultaneously omitting obstacles. The key issue when solving the task is to perform a movement in a collision-free way whilst the planned path should be optimal under some criteria [Trojnacki, 2008].

Going towards a goal point task fall into three consecutive phases: building environment representation, localization, movement planning and movement implementation [Ghorbani, 2009],[Wang, 2008]. In some cases building environment representation is overlooked [Xing-Jian, 2005]. It is justified in these situations when the dynamics of environment changes is comparable or greater than dynamics of map generation and decision-making process. In such cases generated map is not a reliable source of information since it is not up-to-date.

Localization process is based on the knowledge of static environment map, different types of inertial systems, satellite based navigation, heading sensors etc. The usage of odometry for localization purposes [Selekwa, 2008] proves correct if only robot performs its movement on a flat surface without skids and when the movement is performed on short distances, as the error accumulates with time. If only the robot runs in the area where sufficient satellites constellation can be seen the localization can be based on satellite navigation systems supported by INS.

Robot path planning can be considered as local or global task. Global methods demand the knowledge of environment map whilst local methods use information about close surroundings. The global map can be available before the start of movement realization or be created during it.

Path planning methods and movement performing use wider and wider artificial intelligence (AI) methods e.g. genetic algorithms [Ghorbani, 2009] for the fact that path planning can be seen as finding optimum for some cost function. For movement execution a fuzzy inference [Van-Quyet, 2008],[Selekwa, 2008],[Wang, 2008] and neural networks [Boren 1988] are preferred. Additionally literature presents reinforcement learning approaches and nature based algorithms e.g. behavioral control. One of the most interesting tendencies nowadays is to join different types of AI methods and to create hybrid solutions [Baturone, 2007].

Autonomous movement realization based on behavioral control deals with orders that are often contradictory e.g. “go to the target” and “omit obstacles” – therefore a hierarchical structure of control block has to be used in such situations i.e. superior control block for behavior coordination and lover-level methods for realization of particular behaviors and controlling of robot’s drivers.

The majority of literature describing autonomous robots movement that deals with laboratory conditions. Examples of these can be found in [Selekwa, 2008],[Wang, 2008]. Only some of publications are concerned on mobile robots or UGVs in open field conditions. It corresponds to the fact that difficulty of solving such problem increases – in every step of path planning - starting from building environment representation and ending on locomotion that has to deal with more complicated terrain since new-third dimension occurs.

For obstacle detection and classification different types of sensors are used. In laboratory conditions ultrasonic [Van-Quyet, 2008] or near infra-red sensors are preferred. That kind of sensors cannot be used in real outdoor conditions because they are very sensitive to variable ambient conditions. Far better results are obtained by the use of laser based sensors [Selekwa, 2008] and recently radars and lidars.

Video cameras can be considered as a special type sensor. Visible light and thermal used for obstacle detection and building environment representation require image processing algorithms [Kyriacou, 2005] demanding however high computational resources.

Obstacle detection devices detect objects that are prominent and are projecting over the ground surface. Rarely hollow surfaces (hole type) are taken into account. In obstacle classification one of key-issue is to single out a human as a specific type of obstacle. It is important if robot can surmount smaller obstacles, then it can treat a laying person as surmountable obstacle. Next type of special-care obstacles are moving objects [Xing-Jian, 2005]. In case of omitting such, robot has to take into account not only the current position, but also the predicted displacement of object.

Special attention that has to be paid to the issue of autonomous movement is to provide robot good viable features in different terrain (e.g. stairway), power autonomy and operator’s post that controls the robot.

## The IBIS mobile robot

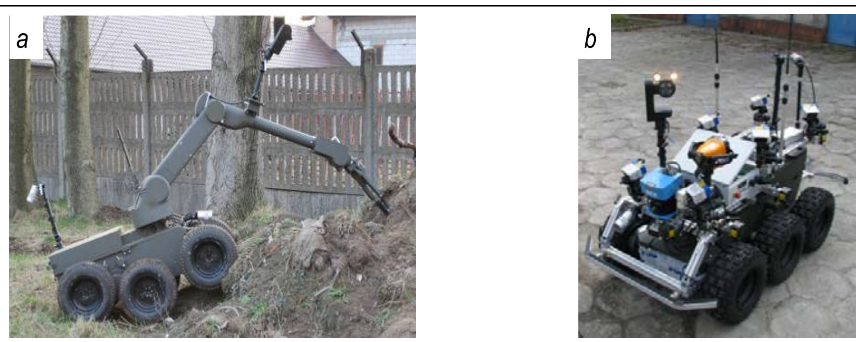


*Figure 1. IBIS mobile robot: the commercial version (a), testbed version for autonomy method development (b)*

The commercial version of IBIS (Fig. 1a) is designed for pyrotechnical and combat missions to operate in diverse terrain like sand, snow or rocky bulk. High speed of the robot allows performing dynamic missions. The manipulator attached to the robot provides long distance operations whilst precision drive system gives fluidity of the movement of every part of the robot, even during fast ride. The basic technical features of the robot are as following: mass: 295 kg, dimensions (length x width x height) 1.3 m x 0.85 m x 0.95 m, maximum velocity: 8.5 km/h, manipulator's maximum load 30 kg, manipulator range: 3.15 m [IBIS, 2010].

For research activity a new version of IBIS robot without manipulator has been designer (Fig.1b).

IBIS robot has been equipped with a frame with sensors forming the modular structure. Sensor's frame is a module that allows operation in semiautonomy mode and it consists of navigation controller which is a main computer of a robot, position controller that provides information about robot's position and orientation, a set of four video cameras and obstacle-sensing devices.

Robot can perform in one of two modes: teleoperation in which the movement of the robot is controlled by the operator, and semiautonomy in which the robot follows a path omitting obstacles.

## Robot's sensors

Mobile base of IBIS is equipped with a sensor's frame that allows precise mounting positions of each sensors, navigation and position controller. The architecture of the system consists of four blocks functionally and physically separated of each other i.e.: sensors, position controller, navigation controller and drivers' controller. The robot control in teleoperation is provided by ISM modem whilst semiautonomy trajectory is fully calculated onboard.

Localization sensors - placed on position controller - are used to determine robot's position and orientation. IBIS position is defined in three dimensions: latitude, longitude and altitude over the Earth geoide according to NMEA specification. Therefore it can be presented in every GIS software.

For actual robot's position an L1 GPS receiver supported by INS has been used. The position in WGS-84 system is achieved by Kalman filtering of GPS coordinates and inertial navigation based on gyroscopes. The azimuth for of true-north readings is provided by digital magnetic compass with tilt compensation. Pitch and roll angles are calculated by inclination sensors: inclinometers and accelerometers.

The frame has been equipped with four types of obstacle detecting sensors: 2D laser scanner, laser rangefinders, true-presence radar sensors and tactile sensors. Their position – shown in Fig.2 – has been settled in the way that sensors cover the whole area around the robot and the main information concerns the area in front of IBIS.

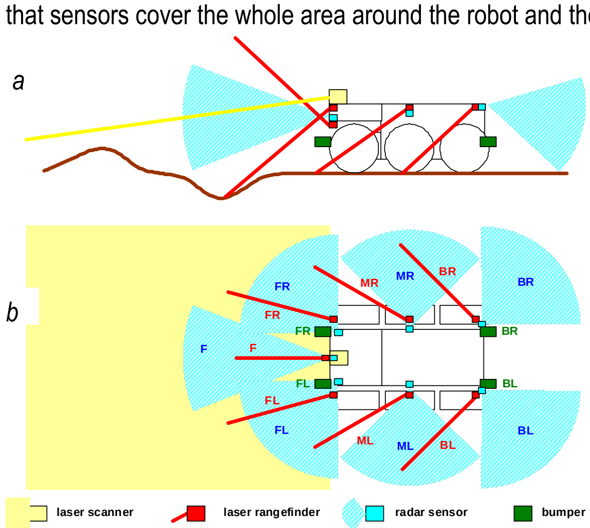


*Figure 2. Orientation and placement of the sensors for semiautonomy mode: left hand side view (a) and top view (b)*

2D scanner's task is to sense obstacles in front of the robot. Its angle scope has been set to 100° and 1° angle resolution. The maximum range is 80 m and is a physical limit of the sensor, but the present LOS depends on the tilt angle of the sensor's beam. For this research the beam is tilted down which allows to sense obstacles below the level of sensor.

Laser rangefinders are used to discover the area in close distance to the robot. They are mounted with different tilt angles that allows sensing obstacles that are both concave and convex. The front rangefinder is pointed with positive tilt which allows sensing obstacles that are too low for the robot to enter underneath.

Radar true-presence sensors are dedicated to sense obstacles in long distance (15 m). They output the binary information whether the obstacle is present or not on the beam. They allow obstacles early notification.

Tactile sensors' task is to sense the obstacles passed over the former sensors and to stop the robot in case of emergency hit.

## Teleoperation mode

Teleoperated motion in the research is performed with a usage of operator's post that consists in laptop, joystick, emergency stop button and communication module.

In dedicated software on the operator's post a view from cameras are presented (single camera, PiP and quad modes), the map of terrain, sensors indications and robot's orientation in form of artificial horizon window. With the help of this application both teleoperation and semiautonomy modes are realized. The change between these two modes is made with a help of single button.

The robot control in teleoperation mode is performed by joystick position change or/and keyboard buttons. The joystick allows also change in position of main PTZ robot's camera.

## Semiautonomy mode

None of presented in the literature autonomy algorithms ensures faultless operations. This is due to the fact of the impossibility of predicting each type of situation whilst sensors are not able to detect and classify all kind of obstacles. For this situation autonomy movement idea was replaced by semiautonomy that describes a situation in which robot performs its movement whilst the operator supervises it and robot's activity can be interrupted in every moment.

The main aim of research presented in this article was to create simulation environment and elaborate an algorithm that would allow IBIS to omit obstacles and simultaneously reach particular destination point.

The software module responsible for global path planning is installed on the operator's post and is based on the map of surroundings where robot's position and planned trajectory are drawn. The maps consists of number of layers what contain information about buildings, roads, rivers ect. Additionally several layers are editable which allows robot trace drawing, or placing points of interest with description. The robot's trace consists of an ordered set of points without the limit in number. The information about nearest intermediary or final destination point is provided to the robot which is a base of semiautonomy movement.

The local movement in semiautonomy is fully calculated by the software and hardware on the mobile robot. The semiautonomy module allows performing one of multiple behaviors such as "go to the target" or "go to the target omitting obstacles".

In case when radars and tactile sensors sense no obstacle the movement is performed with full speed and "go to the target" behavior is executed.

Default and Threshold values of laser sensors are ones that decide whether the sensed obstacle has to be omitted or just surmounted. DefaultValue contains information about regular terrain for particular sensor mounting i.e. when robot is placed on flat surface. Threshold value defines the maximum height/depth of obstacle that can be surmounted by the robot. It is assumed that IBIS can easily surmount obstacles of 20 cm height/depth.

In situation that some obstacle has been sensed robot switches its behavior to „go to the target omitting obstacles" and discriminates the velocity of movement according to distance to obstacle. For mention behavior a hybrid method is used in which the movement is realized based on sub-behaviors. Each sub-behavior defines different wheels control and has a particularly set weighting function in total robot behavior.

The first sub-behavior is connected with setting robot's heading towards destination point.

The second one is connected with setting the value of velocity that depends on the distance between robot and nearest obstacle.

The third behavior is connected with laser scanner, that is treated as 101 single laser beams. For data processing a modified version of VFH method [Boren 1988],[Ulrich, 1998] is used.

Data gathered from laser scanner are compared with corresponding DefaultValues. The next step is to build polar histogram based on prefiltered values. Histogram is then modified to take into consideration robots dimensions. The next step is to find valleys in the histogram and their middle points that correspond to new possible robot headings. The valley that is closest to the aim is chosen as a next heading of the robot.

If all laser scanner beams are occupied by the obstacles a new heading is calculated based on the distance of two extreme beams and the robot turns towards the beam of higher distance to obstacle.

The fourth behavior is connected with laser rangefinders. The wheels control for each side of the robot is in this case calculated as a weighting sum of lasers indications multiplied by weighting factor for particular sensor.

This sub-behavior is patterned on Braitenberg algorithm that bases on direct connection of sensors with actuators where each sensor has its own weighting factor.

The indication of each sensor is multiplied by appropriate weighting factors that for both sides of the robot are modulusly equal but with opposite signs.

Sensors placed on the left hand side of the robot have positive weighting factors for left hand side wheels and negative for right ones which lead to the situation where in case of obstacle sensing robot turns is a proper direction avoiding collision.

Described method of „go to the target omitting obstacles" behavior realization does not always lead the robot to the destination point. In some cases change of behavior (e.g. for "follow the obstacle on the left hand side" behavior) is necessary. The failure of particular behavior is indicated by a mechanism called Water Tank. As the robot moves towards the goal i.e. a distance between current position and destination position is decreasing with a speed over some threshold the virtual water container is empted and if this speed is below threshold the container is filled up. Therefore if current behavior is not effective in leading the robot towards goal the container is overflowed and behavior switch appear.

The next behavior selection is made based on quality estimation of current situation e.g. if during "go to the target omitting obstacles" behavior there are obstacles in front whilst the destination is places in the front-right side the robot can switch to "follow the obstacle on the left hand side" behavior. After the behavior is switched the Water Tank is emptied.

## The simulation research

A dedicated software environment has been created for autonomy method testing and evaluating. It is based on Matlab/Simulink package. This approach allowed to parallel work concerning mobile base assembly and semiautonomy method elaboration.

The software responsible for surroundings simulation and virtual sensors indications has been separated from semiautonomy method. The latter one was written in the way that ease migrating the code to navigation controller's microcontroller.

The robot's surrounding was prepared with a help of V-Realm Builder (Fig.3).

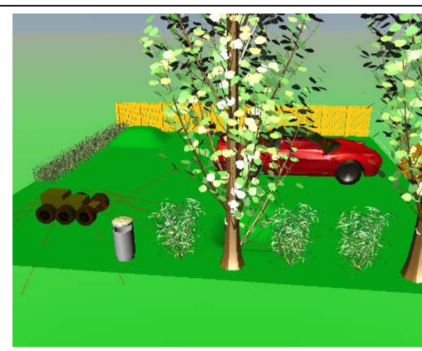

*Figure 3. An example view of robot's surrounding built in V-Realm Builder*

During simulation research, robot's behavior was tested under variety of conditions and sensor's placement on the mobile base. Both convex (e.g. trees, railings) and concave (holes, pits) obstacles were taken into account. In this article, results of one simulation have been presented. On the robot's path four obstacles existed and robot executed "go to the target omitting obstacles" behavior.

Simulation results are presented in Fig. 4. The animation of robot's movement can be found in [youtube, 2010]. The laser rangefinders in Fig. 4e are labeled in the same way as in Fig. 2 whilst laser scanner beams are marked in the way that L$\alpha$, where $\alpha$ is an angle in ° denotes a particular beam of $\alpha$ displacement from longitudinal axis of the scanner. For a clear view, every 10th beam indication of the scanner is shown in Fig 4f.

Basing on a performed simulation one can say that elaborated method allowing omitting obstacles and getting to defined destination point. Robot follows a path with variable speed: the speed is decreased, as the robot gets closer to obstacle (Fig. 4c). During the whole movement, the distance to obstacle is decreased (Fig. 4b). During the movement, the readings of all sensors are being changed. The effectiveness of this approach can be evaluated by Water Tank value that has highest number whilst robot is among obstacles (compare Fig. 4c and Fig. 4b).

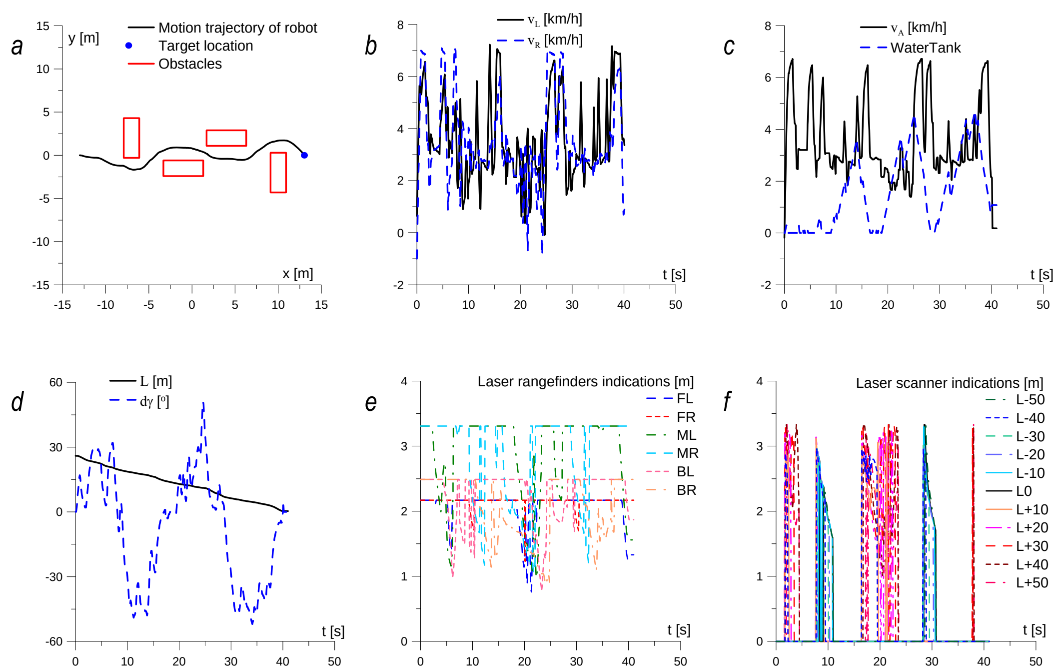


*Figure 4. Data plots from simulation results: robot's trajectory (a), linear velocities values (b), IBIS's velocity and Water Tank parameter value (c), the distance to the target and robot's heading error (d), laser rangefinders indications (e), laser scanner indications for 11 beams (f)*

## The experimental research

During experimental researches a „go to the target omitting obstacles" behavior have been tested for different obstacles placement configuration.

The result from example of experiment is illustrated in Fig.5 whilst movies from omitting obstacles can be seen at [youtube, 2010]. The method can be used in real operation which is based on assessment of trajectory of movement of Fig. 5a that leads robot to the aim preserving safe distances from surrounding obstacles. In Fig. 5b, one can see signals controlling the robot for left and right side of it. It has to be noted that robot is a nonlinear object. It is caused by the fact of nonlinearity of suspension system and skids when making a turn that is in following connected with its kinematical structure. Therefore, the velocities of wheels differ from the control level.

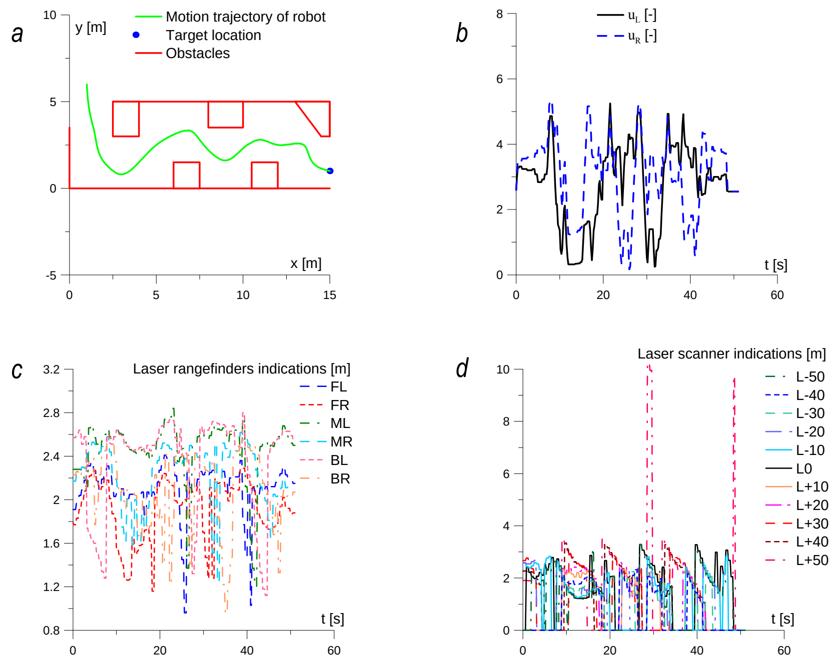


*Figure 5. Experimental results: approximated robot's movement trajectory with starting and destination point (a), left and right wheels control signals (b), laser rangefinders indications (c), scanner beams readings (each 10th beam) (d)*

## Summary and conclusion

In the scope of presented work a computational effective semiautonomy method of the target approaching and obstacle omitting based on data fusion from different types of sensors is presented. This method can be applied to mobile robots that operate in highly urbanized terrain where robot mostly deals with flat terrains, but also for natural environment with its characteristic terrain's shape. Due to different sensors usage and their proper positioning obstacles of different cubature are sensed.

Simulation research has been held for elaborating method. These simulations were carried out using Matlab/Simulink package. Then, the method was optimized in sense of computational requirements and finally implemented in embedded system for checking the convergence of simulation and real robot operation in complex environment.

For the need of experiments a set of mobile robot and operator's post that create complete evaluation system for autonomy method testing have been designed. Modularity of software allows implementation of different other autonomy methods so that IBIS can be used as a testbed for autonomy movement and different method assessment.

Simulations and real experiments show that the method can effectively realize the behaviors „go to the target omitting obstacles" and „go ahead omitting obstacles"

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