Algorithms of Landmark Robot Navigation Basing on Monocular Image Processing

Vasyl Koval

Department of Information Computing Systems and Control, Ternopil National Economic University, UKRAINE, Ternopil, 8 Chekhova str., email: vko@tneu.edu.ua

Abstract: **The application of mobile robots is very important in environments that are dangerous or inappropriate for human life. One of the problems arising for the mobile robot when targeting point within the indoor application during navigation is the provision of its localization. In this paper, the developments of the algorithms that provide and enable mobile robot to position itself within the indoor environment by using one video camera and a landmark template is presented.**

Keywords: **mobile robot, robot navigation, navigation algorithm, mobile robot localization, landmark-navigation, indoor mobile robot navigation.**

I. Introduction

One of the most popular application for mobile robots (MR) is providing navigations in environments in which humans can't be present or environments that are dangerous to human's health [1,2]. The interaction of MR with the operating environment is provided by the application of a number of sensors for the perception of it, actuators (effectors) for influencing the environment and a control system that allows robot to perform purposeful and useful actions. By analyzing the indoor application of mobile robots, it is possible to conclude that its activities in the environment can be considered as a cyclic system.

Within the main loop, MR executes the procedures for the perception of the environment state, process the received information and determines actions that changes its position in the environment according to the fixed purpose. Thereafter, MR analyze changes and the information about the new environment state obtained is send to the control system. Due to these processes being executed, a new loop of mobile robot activities is organized till the purpose will be reached [3].

The actual problem is the creation of mobile robots that are capable of independently navigating and autonomously performing the assigned tasks. At the same time in most cases, humans provide remote control for the MR [4]. Such state is determined by the inability of the robot to make independent decisions and as a result, it provides number of shortcomings and increases the probability of erroneous actions. In addition, it is usually problematic for people to correctly assess the situation on a telemetry data basis and implementation of adequate control. These shortcomings can be avoided if the MR control by humans will be carried out at the level of goal setting, but not at the level of the task execution for individual movements. In this case, the robot must independently (or with minimal human impact) perform the assigned tasks. [5,6].

Typically, the technical vision system is used by MR during navigation. There are three strategic levels for reaching target point of movement by MR and they include: a) corresponding to the far, b) middle and d) near navigation. To be capable of providing such navigational levels, it is significant to develop some algorithms and tools that could support robot to estimate its position or localize at the operating environment.

II. Problem Formulation

One of the core task for robot's navigation is the determination of the MR position and orientation (often referred to as the pose) in its environment. The basic principles of landmark-based and map-based positioning also apply to the vision-based positioning or localization, which relies on optical sensors in contrast to ultrasound, dead-reckoning and inertial sensors.

Most localization techniques provide absolute or relative position and/or the orientation of sensors. Techniques vary substantially, depending on the sensors, their geometric models and the representation of the environment [7,8].

The geometric information about the environment can be given in the form of landmarks, object models and maps in two or three dimensions. A vision sensor should capture image features or regions that match the landmarks or maps.

The MR positioning means finding of the position and the orientation of a robot platform globally in the environment. Usually for this purpose of various types of range, finders are used. Finders have large numbers of drawbacks, the main one among them is that the finder can focus only on the configuration of the working area and the problem of localization (determining coordinates) is solved with errors.

Moreover, the traditional navigating systems usually use odometers for positioning of wheeled platform in an environment. They determine the path traversed by each of the wheels of robot. As a result, such approach leads to accumulated errors. Therefore, the practical problem is to create tools and algorithms that allow mobile robot to provide positioning for movement to the target.

Therefore, the ideal sensor for solving the distinct problems listed above is the video camera from the vision system of the robot. The proof of this statement may be human visual system. In this scientific report, the main attention focuses on the approaches that use photometric vision sensors, i.e., cameras for MR positioning.

In robotics, it is possible to find the implementation of stereo cameras for similar applications. Two or sometimes three cameras and special image processing techniques are used to reconstruct the robot's environment [9]. Stereo image processing has its drawbacks. The main one among them is finding the correspondence between two stereo images that is very complicated. Moreover, the authors of these methods often simplify the process by creating artificial landmarks, including the usage of different kinds of structured lights, etc. At the same time, in nature there are many organisms that have successfully provided orientation in the environment by using only one video-sensor. This fact creates prerequisites for research methods for analog behavior in technical systems.

To address practical issues of the task definition, we will consider some of the environment in which mobile robot operates at industry (Fig. 1) [10].

Fig.1. The operating environment of mobile robot at industry [10]

In that environment, it is quite difficult to localize robot. Moreover, MR needs to determine its position independently for provision of the navigational goal, subsequently, to deliver the goods or perform other necessary operations.

Based on the above mentioned practical needs, it is proposed that the development of algorithms and software units use one camera and image processing technique to easily solve the task of positioning the mobile robot in the environment during the movement to the target.

III. Idea of the Proposed Algorithm

The idea of the Proposed Algorithm is to study and solve problems. Let us consider the technology that is taken from nature when organisms are oriented in space through various beacons (example: the sun). For this purpose, one of the possible solution of the previously mentioned task is proposed to fix a landmark on the ceiling of the technological environment where the mobile robot operates. In a situation wherein, the coordinates of landmark are known, there is a need for algorithms and software units of the image processing that will determine the robot's position in the environment.

Thus, the following geometric interpretation is proposed to solve this task (Fig. 2). According to Fig. 2, a special situation is proposed, when on the base of the mobile robot platform the video camera is fixed and directed vertically upward. Thus, the location of mobile robot platform determines by the position of video camera. The camera is located at some distance from the ceiling *OM* (Fig. 2). Any point located on the ceiling is projected through the center of the camera lens (point *O* o Fig.2) to the sensor panel (plane *ABDC* on the Fig. 2). For localization of the mobile robot in the environment, the landmark template is fixed on the ceiling and has coordinates known as (*X2*, *Y2*). To perform the movement of the mobile robot to its target, it is necessary to find its location in the environment (it is necessary to search the coordinates of points (*X1, Y1*) and the angle "*Alfa*") basing on the projections of landmark to image. As part of the robot localization, one of the practical task is the identification of landmark on the image from the video camera.

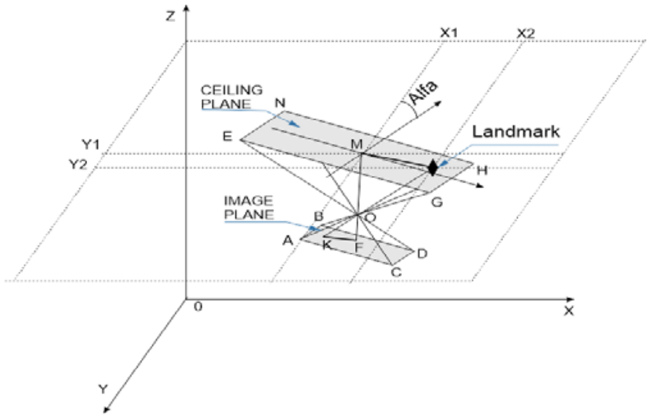

Fig.2. Geometric interpretation of the task definition

Thus, the input data for the developed algorithm and software units are color RGB images obtained by the robot's video camera. For the solution of the task that is given above, the following restrictions and assumptions are considered:

- a preliminary calibration of the camera was done. Due to the result of the video camera calibration, its position is fixed onboard of the mobile robot platform and does not change during operation;
- MR provides movement in a straight and flat horizontal surface like a floor, which practically represents a homogeneous coating (laminate flooring, linoleum, construction coupler);
- there are no overhanging objects that could cause a collision with a mobile robot in the environment;
- a landmark template exist in the environment with known parameters and it is visible for mobile robot;
- within presented restrictions, the operating three-dimensional model of the environment that is presented on Fig. 2 is considered.

The expected output of the algorithm is the selected segment of the landmark template at the image plane, which is used to calculate the trajectory of mobile robot movement to the target point.

Thus, to achieve this task, it is proposed to use the video camera as an effective passive sensor. By using this, the mobile robot will provide the proper positioning in the environment on the way to the target point.

IV. Generalized Algorithm of Mobile Robot Navigation Based on Monocular Image

In general cases, the navigation of MR to the target is provided by using image processing from one camera. The robot navigation consists in analyzing of the current robot location and local targets that follow to global position. These local targets can be displayed as a line or landmarks representing a sequence of intermediate links that should follow the robot. Sometimes, there is a situation wherein the robot has only one global target to achieve. In this case, the movement of mobile robot must be ensured, taking into consideration the possible local obstacles or static architectural designs of the environment. Local movement to the target may be provided by one of the known methods that are based on local or global navigation [11, 18]. Within this scientific work, the local movements of mobile robots are not considered, but it considers the algorithm by which the robot determines its position for predicting the direction of movement to the target as a subtask of robot navigation.

For simplicity in the consideration of the above presented principles of robot navigation, let consider the robot environment as grid-based model. In this environment, the coordinates of the target point are given, which represents the goal of the robot movement. The ultimate purpose of a robot navigation is to build a direction (trajectory) of movement to the global target point and to generate the control commands, which defines the required acceleration of MR wheels for maneuvering. The navigation task is completed when the robot is within a certain range with respect to the point of global goal.

For the provision of the above presented way of robot navigation, unlike existing known local methods of navigation [12-15], it is proposed to take the appropriate decisions for the direction of MR movement at each step in a loop. Thus, the decision to bypass obstacles and direction taken at each iteration of a loop depends on the location of the landmark on the image of the robot's camera. The main processes provided by mobile robot for navigation to its target can be presented by generalized algorithm and it consist of the following:

1. At the first step, there's an execution of the image processing procedures that initialize values for algorithms and provide camera calibration procedure.
2. At the second step of the algorithm, the position of the mobile robot platform (coordinates of its center point) and the target position are determined. The vector of the length between the point of the robot's position and the point of the target's position is determined (the distance to the target).
3. If the position of the mobile robot is within a certain radius delta (the concrete value is specified during the initialization procedure) from the target point, then it stops working and take a decision of reaching the goal of movement. In this case, the algorithm of mobile robot movement is finish. This moment represents the stop-point for the MR navigation algorithm.
   Otherwise, the following sequence of steps are executed:
4. Gathering of the video-frame from the robot's video-camera.
5. It performs the segmentation of landmark template on the image received previously from the video-frame. Thereafter, the coordinates of the central point of the landmark template are calculated at the local coordinate system of the image.
6. It provides calculations of the directional angle of the Mobile Robot's position relative to the placement of landmark template that is segmented on the image from the video-camera.
7. It is performing the procedure of calculating the distance from the position of mobile robot to the central point of the landmark template.
8. It Performs the procedure of the MR positioning at the manipulating environment.
9. Based on the coordinates of the target and the position of the MR at the manipulating environment, it performs the procedure for defining the direction of movement.
10. Providing the MR maneuvering, based on the necessary parameters of acceleration for the MR motors. As a result, the movement of the robot's platform provides changes to its position in the environment (its coordinates).
11. Return to step two.

The flowchart of generalized algorithm is given on Fig. 3.

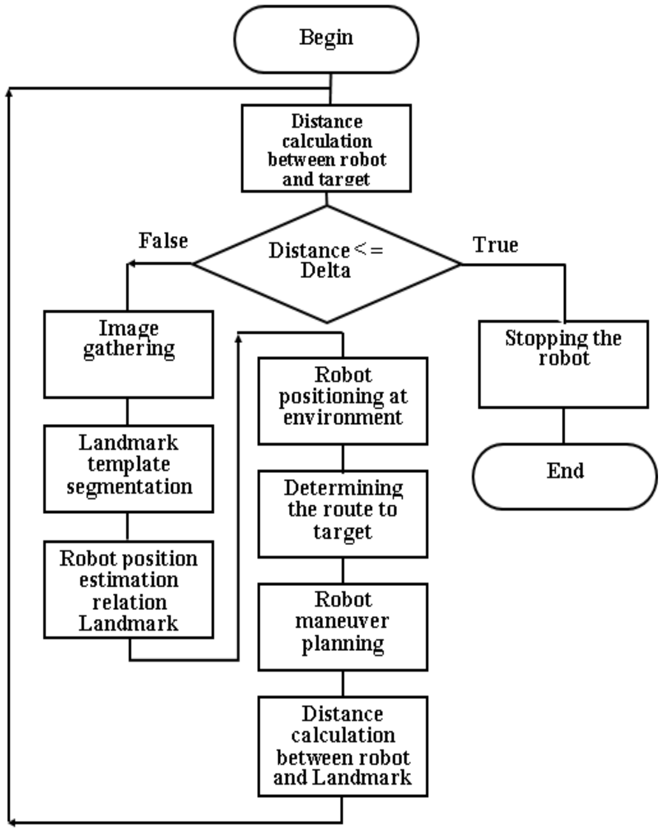

Fig.3. Generalized algorithm of mobile robot navigation

V. Landmark Template Detection on The Image Plane

During navigation, the MR estimate its location and position in the environment based on the landmark position. The last one, it is possible to receive based on image processing from one robot's video-camera. It means that the orientation of the given landmark of the images allows determination of the position of the robot's platform and as a result it provides smooth navigation.

In accordance to the list of steps presented above in the generalized algorithm, one of the first process of robot navigation is to capture a video frame from video camera. Performances of these steps can take place using existing and known possible approaches. At the same time, it is necessary to design the methods that can detect landmark template on video-image. To identify the landmark template for mobile robot navigation, it is proposed that algorithm is used to perform the following procedures (Fig. 4):

The RGB-image that receives from color video camera represents input for algorithm execution. The algorithm mentioned above selects some areas of pixels on the image (image segment) that belongs to possible landmark template that are selected. Thereafter, it is applying the procedure of rejecting all other than landmark template segments by using the various metrics. As the result of the algorithm, the image segment of pixels that respond to landmark template is selected.

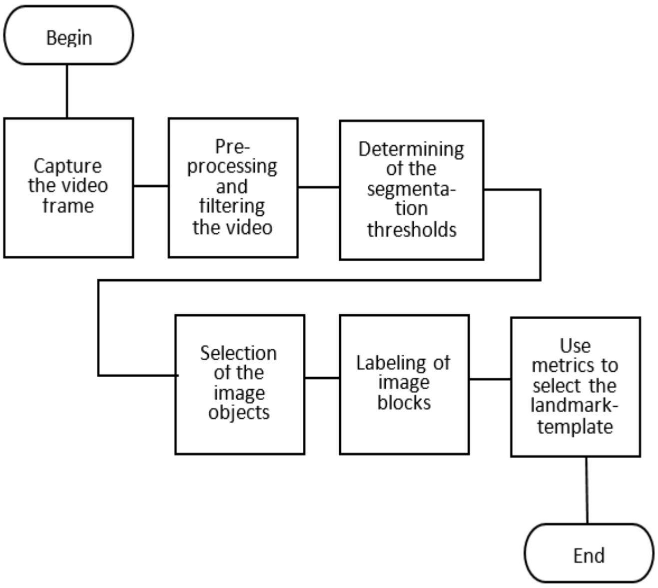

Fig.4. The algorithm for landmark template detection on the image plane

VI. Algorithm Implementation

The above designed algorithms for robot navigation was explored by using Mat-lab software. The implementation of all processes that provide MR navigation to its target is currently under development. The conceptual interest of researches consists of obtaining the stable segmentation of landmark template for MR pose estimation in the environment. During researches, many navigation procedures could be implemented by the application of specific functions that are appropriate for the MR configurations individually, depending on the type of robot. For example, it could be possible to use ARIA environment for robots from ActivMedia Robotics Company [19, 20] (Fig. 5).

Fig.5. One video-camera application for navigation of mobile robot Pioneer P3-DX (potential application) [21]

Let consider the implementation of algorithm for landmark template detection on the image plane (Fig. 4) as the most important part for landmark robot navigation.

All the processes done were formalized mathematically for the investigation and implementation of the algorithms mentioned above. Also, it was designed specific graphical representation of the landmark template (Fig. 6a). The shape of landmark allows unique identification among other objects of the image, and to determine angular orientation on the global environment map. Additionally, the three metrics for guaranteeing the selection of landmark template among the other segments on the image plane were suggested:

- the number of pixels in the segment;
- the distance between the most remoted pixels in the segment;
- the presence and number of holes in the segment.

To investigate and demonstrate algorithm, a special situation of landmark location on the ceiling of MR environment was taken (Fig. 6a). As it could be seen on the image captured by the video-camera, there exist additional object (lighting lamp). Such object could be located at the range of the camera's vision and needs to be removed as unwished for processing. Median filter with 3x3 matrix operation were applied to each image pixel on Fig. 6a.

According to the algorithm of landmark detection, the following values of thresholds were selected for red, green and blue colors: *R_Tresh*=75±28, *G_Tresh*=95±10, *B_Tresh*=133±10. The result of image thresholding presents on Fig.6b.

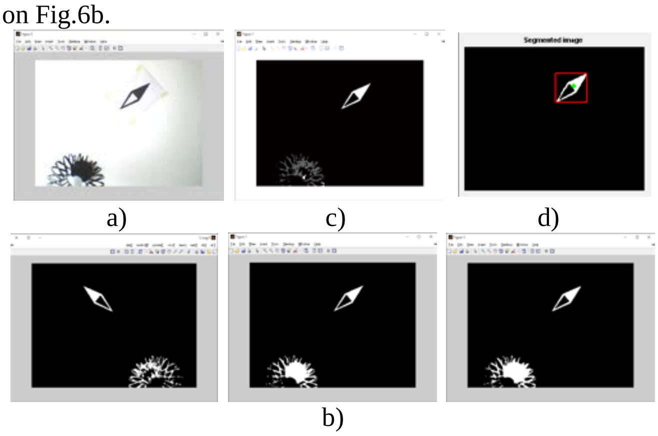

Fig.6. Results of image processing: a) the input image; b) the results of thresholding in the red, green and blue spectrums; c) result of labeling of segmented image (there are 58 objects indicated by different colors); d) the result after applying metrics

The initial image was binarized by combining of the segmented images on Fig.6b. During the processing of the neighbor-segmented pixels at the initial image, 58 segments were selected as candidates to be landmark template for MR navigation (Fig.6c).

Thereafter the following values were experimentally selected for proposed metrics: the number of pixels in the segment (2200-3120); the distance between the most remoted pixels in the segment (150±10); the presence and number of holes in the segment (3 holes).

The result of applying mentioned metrics in the proposed algorithm of detecting the landmark template on the image is shown on Fig.6d. As it was expected, only one segment among the plurality of image objects were selected. It includes 2436 pixels and three holes. The distance between the most remoted points is 147.

Experimental studies have shown the usage of a sufficient metric for identifying landmark template at 200 different locations at the environment.

The actual representation of the algorithm scenarios will be demonstrated during the presentation.

VII. Summary And Conclusion

In this paper, algorithms of mobile robot movements were developed and experimentally investigated by using a one video camera. This practical task was reached by applying localization techniques using landmark template detection.

The generalized algorithm that allows mobile robot to move to the target was developed based on reading from one video camera and image processing procedures.

The graphic template of landmark was designed, which allows the MR to identify its position as the image among other objects and allows it to determine angular orientation on a global environment of mobile robot.

The algorithm for landmark template segmentation was designed based on the image processing that allows the MR to identify its position on the image plane. By knowledge of the position of landmark template in the environment, it is possible to localize mobile robot.

The experimental studies of the proposed algorithm of landmark template detection on the video images have shown the stability on each algorithm step and provided a selection of one segment among the plurality of image objects.

References

[1] Robla-Gómez S., Becerra V., "Working Together. A Review on Safe Human-Robot Collaboration in Industrial Environments", *IEEE Access (*Vol. 5), November 14, 2017, pp. 26754–26773.

[2] Baudoin Y., Habib M., "Using Robots in Hazardous Environments", 1st Edition, Woodhead Publishing, 2010, P. 692.

[3] Evans, J., PatrUn, P., Smith, B., Lane, D.M., "Design and Evaluation of a Reactive and Deliberative Collision Avoidance and Escape Architecture for Autonomous Robots", *Autonomous Robot* Vol. 24, 2008, pp. 247–266.

[4] Goebel S, Jubeh R, Raesch S-L & Zuendorf. A. "Using the Android Platform to control Robots", *In Proceedings of 2nd International Conference on Robotics in Education (RiE 2011)*. Vienna, Austria, September 2011, pp. 135-142.

[5] Siegwart, Roland, Nourbakhsh, Illah Reza, "Introduction to Autonomous Mobile Robots (Intelligent Robotics and Autonomous Agents series)" / Siegwart, Roland, Nourbakhsh, Illah Reza, Scaramuzza, MIT Press; 2nd Revised edition, 2011, P.453

[6] Siciliano Bruno, Khatib Oussama "Springer handbook of robotics", Springer International Publishing, 2016, P. 2227.

[7] Arras, K.O., Castellanos, J.A., Schilt, M., Siegwart, R., "Feature-based Multi-hypothesis Localization and Tracking Using Geometric Constraints", *Robotics and Autonomous Systems 44*, 2003, pp. 21-53.

[8] Betke Margrit, Gurvits Leonid "Mobile robot localization using landmarks", *IEEE Transaction on robotics and automation*, Vol 13, No. 2, April 1997, pp.251-263.

[9] H. Roth, A. Sachenko, V. Koval, O. Adamiv, V. Kapura, "Evaluation of Camera Calibration Methods for Computer Vision System of Autonomous Mobile Robot", *Proceedings of International Conference "Modern Information and Electronic Technologies" (MIET-2009)*, Odessa (Ukraine), 2009, p. 29.

[10] "Are Robots About to Take Over E-commerce Warehouses?", 2018, http://www.airindknows.com/are-robots-about-to-take-over-e-commerce-warehouses/.

[11] Jian, Y., "Comparison of Optimal Solutions to Real time Path Planning for a Mobile Vehicle ", by Y. Jian, Q. Zhihua, W. Jing, C. Kevin, *IEEE Transactions on Systems, Man and Cybernetics*, Part A, System and Humans, Vol. 40, 2010, pp. 721–725.

[12] Ersson T., Hu X., "Path Planning and Navigation of Mobile Robots in Unknown Environments", *IEEE Journ. of Robotics and Automation,*.# 6, 2010, pp. 212–228.

[13] J.L. Guzmán, M. Berenguel, F. Rodríguez, and S. Dormido, "MRIT: Mobile Robotics Interactive Tool" [electronic resource], 2018, http://aer.ual.es/mrit/.

[14] O. Adamiv, V. Koval, V. Dorosh, G. Sapozhnyk, V. Kapura, "Mobile Robot Navigation Method for Environment with Dynamical Obstacles", *Proceedings of the IEEE Fifth International Workshop on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications*, 21-23 September 2009, Rende (Cosenza), Italy, pp. 515-518.

[15] Chernonozhkyn, V.A., "Local Area Navigating System for ground mobile robots", *Scientific and Technical Journal YTMO St. Petersburg State University*, 2008, №57, pp. 13-22.

[16] Oleh Adamiv, Vasyl Koval, Arunas Lipnickas, Viktor Kapura, "Local navigation method for improvement of mobile robot movement", *Proceedings of the 3rd International Conference Mechatronic Systems and Materials (MSM 2007)*, Kaunas (Lithuania), 2007, pp. 245- 246.

[17] William Benn and Stanislao Lauria, "Robot Navigation Control Based on Monocular Images: An Image Processing Algorithm for Obstacle Avoidance Decisions", *Hindawi Publishing Corporation Mathematical Problems in Engineering*, Volume 2012, P.14.

[18] Olivier Koch, Matthew R. Walter. "Ground Robot Navigation using Uncalibrated Cameras", *In Proc. IEEE International Conference on Robotics and Automation (ICRA)*, May 2010, pp. 2423-2430.

[19] Adept Mobile robots, 2014,: http://www.activmedia.com/.

[20] "AmigoBot Operations Manual, revision 4.3", 2018, http://robots.mobilerobots.com/wiki/Manuals.

[21] "Mobile robotics platforms", 2018, https://raweb.inria.fr/rapportsactivite/RA2015/lagadic/uid51.html.