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Mapping of unknown industrial plant using ROS-based navigation mobile robot

G. Priyandoko¹, T. Y. Ming¹, M. S. H. Achmad²

¹Faculty of Mechanical Engineering, University Malaysia Pahang (UMP), Pekan 26600 Pahang, Malaysia

²Universitas Teknologi Yogyakarta, 55285 Sleman, Yogyakarta, Indonesia

*Corresponding author: gigih@ump.edu.my

Abstract. This research examines how humans work with teleoperated unmanned mobile robot inspection in industrial plant area resulting 2D/3D map for further critical evaluation. This experiment focuses on two parts, the way human-robot doing remote interactions using robust method and the way robot perceives the environment surround as a 2D/3D perspective map. ROS (robot operating system) as a tool was utilized in the development and implementation during the research which comes up with robust data communication method in the form of messages and topics. RGBD SLAM performs the visual mapping function to construct 2D/3D map using Kinect sensor. The results showed that the mobile robot-based teleoperated system are successful to extend human perspective in term of remote surveillance in large area of industrial plant. It was concluded that the proposed work is robust solution for large mapping within an unknown construction building.

1. Introduction

Inspection robots enable operators to plan outages more precisely and efficient and thereby reduce downtime. This increases the availability of facilities and makes them more profitable, as well as boosting the safety of people and the environment. Eliminate human entry in confined spaces and perform the inspection from a safe & remote location. It can save the life of workers and allows the operator to access areas that could not be accessed by human, get more coverage, inspect behind baffles and obstacles.

While performing inspection, mapping is an important step when a mobile robot wants to explore the unknown environment [1-3], and the robot should be able to move and find the pathways to avoid obstacles and achieve the goal. Mobile robot navigation technology is now increasingly sophisticated, with the technology of 2D/3D mapping [4]. Many studies have been done on the implementation of 2D/3D SLAM (simultaneous localization and mapping) to determine the goal position respect to the current position of the robot in an area that has not been recognized previously [5]. The differential mobile robots are commonly used among researcher due to the ease of kinematic run in a narrow area, as in the halls of industrial plant.

ROS is an open source framework which has the capability to handle all software layers from low-level up to high-level layers. Because of that, everyone all over the world can build and share ROS stack and package for certain purposes. High demand on ROS stack from researchers was increasing exponentially the number of ROS stack production year to year. Therefore, ROS provides better methods which were can be chosen based on our own desires and purposes. It is also the product of trade-offs and prioritization made during its design cycle [6].



The contribution of this work is an industrial inspection solution which is able to describe the environment in the entire industrial plant in the form of large 2D/3D map that can be used for evaluation regard to safety and maintenance issues instead of using captured images or videos. The mobile robot was able to simultaneously localize and build a real-time map more than 2 km² of our robotic laboratory areas less than one hour. The purpose of this experiment was not merely to demonstrate implementation of differential mobile robot for industrial inspection, but also describes the methods how to develop mobile robot platforms run on robust operating system, that is ROS.

2. Differential Mobile Robot

In this study, the differential mobile robot (DMR) is utilized, which commonly used by researchers in addition to the Ackermann model. The DMR has two independent wheel drive system that can be controlled independently and it has a turning radius more varied than the Ackermann, even capable of rotating exactly on the centre of gravity (cog) of the robot body. So the DMR has the manoeuvrability to avoid obstacles better than the Ackermann model in term of narrow space.

Figure 1(a) shows the kinematic model of the real robot shown in figure 1(b) which is accommodates two input, linear velocity (v) and angular velocity (ω) toward the target position. Basically, the DMR model adopts unicycle kinematic model shown in Equation (1-3), as follows:

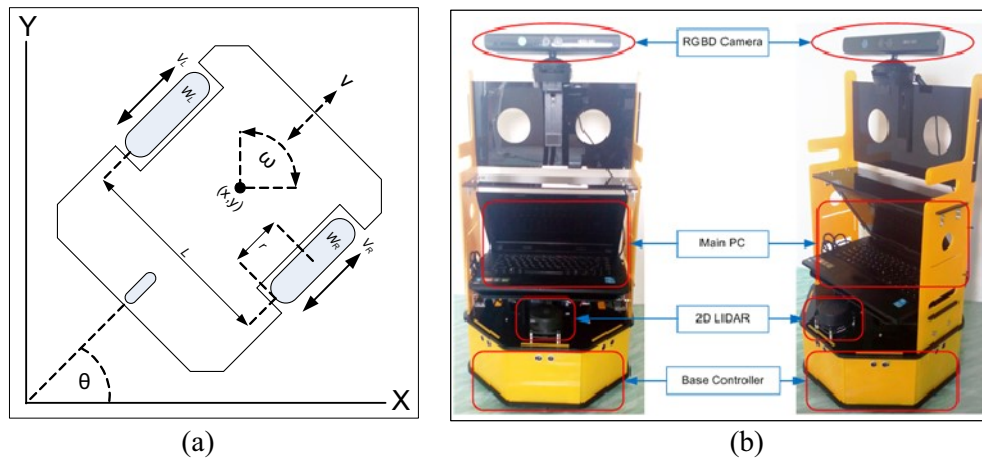


Figure 1. The DMR model used in this study. (a) The kinematic model. (b) The real model.

$$\dot{x} = v \cos \theta \quad (1)$$

$$\dot{y} = v \sin \theta \quad (2)$$

$$\dot{\theta} = \omega \quad (3)$$

(\dot{x}, \dot{y}) and $(\dot{\theta})$ are dynamics position and orientation respectively in discrete time. While in the DMR kinematic model, \mathbf{v} and $\boldsymbol{\omega}$ are obtained from the variations in the speed of the right wheel (v_R) and the left wheel (v_L) simultaneously as shown in Equation (4-6), as follows:

$$\dot{x} = r/2 (v_R + v_L) \cos \theta \quad (4)$$

$$\dot{y} = r/2 (v_R + v_L) \sin \theta \quad (5)$$

$$\dot{\theta} = r/L (v_R - v_L) \quad (6)$$

Where, r denotes the wheel radius, and L denotes the distance between right wheel and left wheel. Thus, between Equation (1-3) and (4-6) are become equal, v_R and v_L can be calculated accordingly as shown in Equation (7-8), as follows:

$$v_R = (2v + \omega L)/2r \quad (7)$$

$$v_L = (2v - \omega L)/2r \quad (8)$$

Based on Eq. (1-8) then the base controller of the robot can translate the twist message from main controller contains linear and angular velocity as set points into speed of wheels for both of the right and the left side as shown in figure 2.

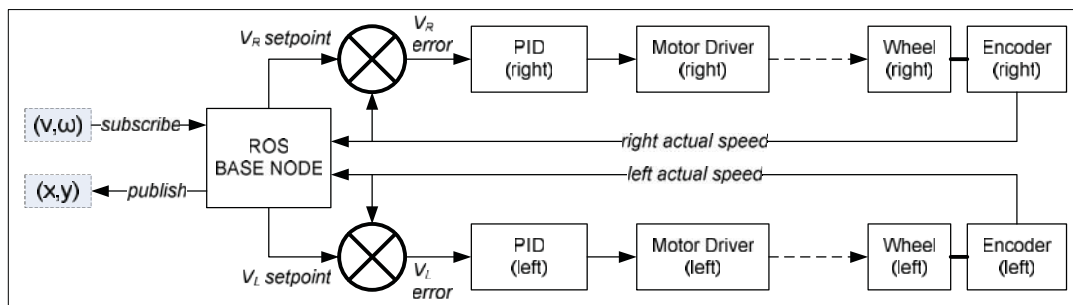


Figure 2. The DMR base controller system connected to the ROS environment.

Figure 2 describes the diagram of base controller system as ROS node. The base controller node subscribes v and ω in the form of `geometry_msgs/Twist` as ROS standard message from the other ROS node as remote operator (human). Simultaneously, `nav_msgs/Odometry` is published by the base controller, which consists of x, y, z ($=0$) obtained from the encoders. The odometry message from the base controller can be used for pose estimation together with laser and visual odometry for better result. ROS `geometry_msgs/Twist` is translated into v_R and v_L based on Equation (7-8) as set points for two PID controllers. Afterward, PID controllers maintain linear velocity and angular velocity of the mobile robot toward the target position as desired.

3. Robot Operating System

Robot Operating System (ROS) is an open source software framework primarily based on UNIX platform for operating robots. It is widely conducted for robotics research in the last decade and an obvious overview of ROS has been presented by [6-7]. ROS has three levels of concepts: the file system level, the Computation Graph level, and the Community level. ROS provides the service user would expect from an operating system, including hardware layer abstraction, low-level device control, implementation of commonly-used functionality, message-passing between processes, and package management. It also provides tools and libraries for obtaining, building, writing, and running code across multiple platforms. The primary goal of ROS is to support code reuse in robotics research and development. ROS is a distributed framework of processes (nodes) that enables executables to be individually designed and flexible at runtime. These processes can be grouped into Stacks and Packages, which can be easily shared and distributed. ROS also supports a federated system of code Repositories that enable collaboration to be distributed as well. Figure 3 shows the basic concept of ROS with distributed system capabilities.

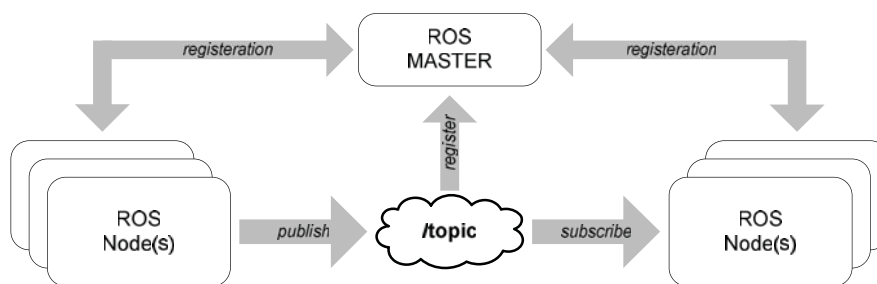


Figure 3. ROS basic concept.

ROS Master served as a major control the entire distribution of messages within the network. Each node will register the identity to the ROS Master include the IP address and the name of the topic will be published or subscribed. When ROS nodes subscribe to a particular topic, ROS nodes will contact ROS master to get the IP address of other ROS nodes which publish the associated topics. The name of topic is unique, so ROS nodes should not publish the topic with the same name in the same ROS network. Relationships between ROS nodes not merely publish and subscribe, but also client-server relationship. ROS node can ask the service (request) to the other nodes to do something and then get the results (response) without processing it themselves. It indicates the advantages of ROS

system associated with the concept of distribution of information, so as to facilitate users to build a robotic system that has a complicated mission with simple solution.

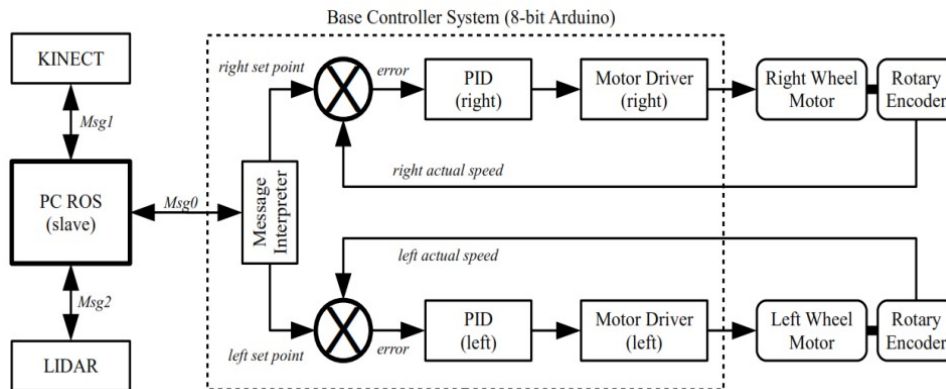


Figure 4. ROS-DMR ecosystems.

In figure 4, PC ROS-slave receives messages from Kinect and LIDAR and transmits a signal to the base controller. The Kinect sensor produces RGB-D image data, laser sensor generates 2D depth scanning data, and the base controller receives two types of input velocity, 3-axis linear velocity (v_x , v_y , v_z) and 3-axis angular velocity (ω_x , ω_y , ω_z). The base controller receives velocity messages were interpreted in two correspondence values of speed (left wheel & right wheel) based on robot kinematics model as seen in equations (1-2). Set points for two PID controllers are $V_{leftwheel}$ and $V_{rightwheel}$ which correspondence with targeted linear velocity and angular velocity given by a PC ROS-slave. Afterward, PID controllers maintain linear velocity and angular velocity of the mobile robot toward the target position. Figure 3 shows the real mobile robot which is completely designed based on model and component configuration as seen in figures 2 and 3.

4. Results and Discussion

The purpose of this study is to develop an interface between the human as an operator with the mobile robot to get information about 2D/3D map in an unknown area. The distributed system of ROS ecosystems makes it easy for people to control the robot remotely and get a lot of information at the same time.

Figure 5 shows the reconstructed 2D map which is compared with ground truth. Apparently, the reconstructed 2D map is sync with ground truth map. Ground truth map does not cover the entire obstacle, just walls, drawers, cabinets, partition board are used as a comparison. The light gray section shows the occupied area, while at the dark gray indicates the area that have not occupied during exploration.

Figure 6 shows the occupied map from explorations in our experiment and visualizes using RVIZ (GUI). A 3D map obtained from Kinect sensor using Octomap was exactly located on the top of 2D map, shows that localization conducted by Hector SLAM was well performed. RVIZ runs on ROS platform which is provides attractive visual interaction facilities to accommodate human-robot interaction impressively. All of the topics from any kind of messages which belongs to nodes are could be obtained by RVIZ. As seen in figure 5 operator can use RGB image from Kinect sensor, kind of nodes contain the topics to be visualized, and 2D/3D map to be analysed as the main purpose in term of human-robot interaction that has been done. The numbering index on the 3D map shown in figure 6 illustrates each robot position when taking a picture using the RGB camera. This information is used to associate a 3D perception with 2D RGB image, and it is enable people to understand the situation around the robot either 2D or 3D.



Figure 5. Constructed 2D map compared with ground truth

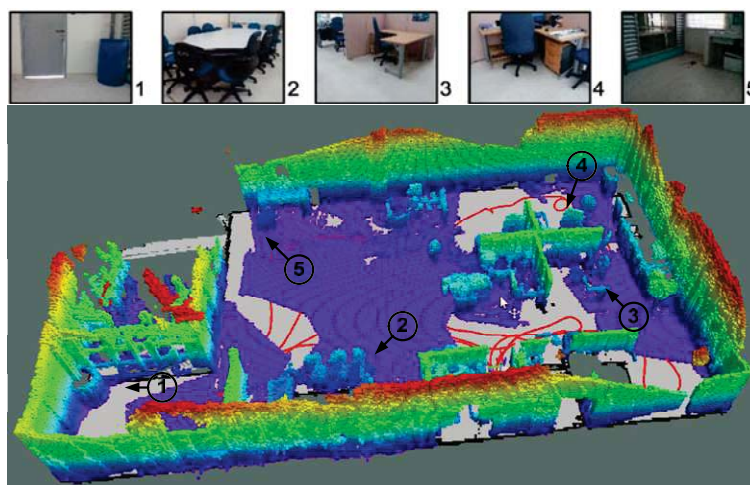


Figure 6. Visualize 2D & 3D occupied map using RVIZ

5. Conclusions

In this experiment, the odometry function becomes a big issue in term of accuracy and precision. Visual odometry which comes up with uncertainty error depends on image features detection and tracking is relying on how SURF algorithm deals with the texture-less object and the acceleration of the camera movement relative to the object. Texture-less area and high acceleration of camera movement produces high error in odometry function. The translation and rotational speed of the robot are the challenges in order to perform the detail inspection resulting low drift 3D map. However, this works has successfully demonstrated the methods how to apply mobile robot on ROS platform in order to performs the exploration and generate the 3D map which can be applied in the remote inspection of industrial plant.

Acknowledgments

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