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An Autonomously Guided Differential Drive Robot Base Using Asus® Xtion Pro Live

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Abstract—**Robots have been popularized in the world during the past two decades and its development has overtaken many tasks performed by people, from households to the largest companies. Further, robotics has its applications in almost all industries and sectors. Robots are available in many sizes, weights, and appearances based on their usage and applicability. In our study, we are going to introduce a novel robot base. We have developed the basic structure of the base using low-cost materials and open-source software packages. We used a 3D vision sensor for capturing the environment. Xtion Pro Live sensor by Asus was chosen for the purpose as it is lightweight, small and can be powered through a USB cable. We selected a Raspberry Pi computer as the processing unit of the base because of its lightweight and low cost. Further, it functions efficiently in an indoor environment using wheels. It is Pentagon shaped, 35 cm long and 30 cm wide. It can carry up to 5 kg in weight. We have tested the robot base in an unstructured indoor environment for goal completion using five locations. The robot's accuracy in achieving its targets is 92%. We have made a prototype of a novel robot base with the intention of developing it to append a robotic arm. The system will be able to mimic the tasks in a storage area, having the ability to add, remove and reposition the items in racks.**

Index Terms—**Robot base, Raspberry Pi, Autonomous Navigation, SLAM, RGB-D Sensor, ROS, Asus Xtion Pro Live**

I. INTRODUCTION

In today's world, robotics is booming, and we can not find a field where we do not use robotics. Therefore, it is now one of the most important areas in the world. There are many types of robots around the world to make human tasks easier.

In Robotics, all robots can be divided into two main groups such as movable robots and unmovable robots. Movable robots do tasks by moving in-between places while the other type performs its task residing in a static position. Movable robots can be further divided into several groups based on the device they use to move. There are three of them as Legged robot: human-like legs (i.e. an android) or animal-like legs, Wheeled robots and Tracks.

This type of robot navigates in an environment to complete its tasks. There are many types of mobile robot navigation including Manual remote or tele-op, Guarded tele-op, line-following Car, Autonomous randomized robot, Autonomously guided robot, and Sliding autonomy.

For a robot to be movable, it must include sensors, motors, and actuators(legs, wheels, etc.). There, sensors are used to capture the environment and targets. These include a camera, laser and lidar, radar, sonar, infrared, touch sensor whisker or bump sensors, GPS and proximity sensors. Proprioceptor sensors deal with the robot itself, such as wheel encoders, accelerometers, gyroscope, magnetometer and compass, and temperature sensors [1].

On the other hand, actuators in robots help to act based on target and perceptions. Hydraulic, Pneumatic, and Electrical are the three types of actuators that are mainly used in robotics, depending on the energy they transform. Electrical actuators or gear motors are key when controlling positions and speeds demanded by several mechanisms and actions for each robot. Their use in a robotics project will depend on the stability we wish to obtain, the weight it needs to carry, the repetition speed, and precision in which the robot would work for among other factors [2].

In this study, we focused on developing an automated guided differential drive robot-base for an indoor environment. Navigable Robotic bases have a high demand in research fields of electronic and embedded systems but there are a limited number of them existing in the current marketplace. Some of robotic bases available on the market are, Turtlebot 1 [3] and 2 [4], ROSbot [5], Pioneer LX [6] etc. However, there are some limitations to these existing robot bases. For example, they are very expensive, limited in carrying capacity, limited in reprogramming ability, inability to change shape, etc. As such, our robot base has minimized the aforementioned complications and it is very profitable and easily re-programmable. Further, it can be easily customized to obtain a desired size.

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Finally, this base can be used for various purposes in research and industrial fields by amending robot arms, stacks, racks and etc.

II. LITERATURE REVIEW

A. Sensors in movable Robot Systems

J. Juang and C. Yang [7] proposed a delivery robot based on image processing techniques and fuzzy controlling. An RGB camera was used to capture the office environment and they compiled it with image processing techniques. This system was functional in light illumination conditions, but not in dark illumination conditions. We use a 3D vision Sensor in our system. As we have addressed in [8] our previous test results with the proposed system, show that it can be used in both dark and light illumination conditions. M. Jalobeanu et al [9] proposed a Kinect-based navigation system in large indoor environments. Here, they used a Kinect RGB-D sensor, Pioneer 3DX robot platform, and LIDAR to build the robot system. Even though LIDAR is the more accurate sensor to build an environment map for robot navigation, it is very expensive. In similar research, D. Sales et al [1] proposed a movable robot in indoor environments using a Kinect sensor as the 3D vision sensor. An extra power source (12 V, 2.67A) is needed in order to satisfy the power requirement for the Kinect sensor. In addition, Kinect needs its own USB converter to connect with a computer. Altogether, the robot has to carry extra weight (cables, USB converters, and battery pack) when implemented with a Kinect sensor.

B. Wheeled Robot bases/platforms

Robot bases can serve as a platform of your robot that builds upon, or just as a test platform for developing/testing new software. They are introduced by many companies to the industry. However, they can be programmed and customized to our needs. Some of them are Husky, Pioneer / PowerBot, iRobot Create, Willow Garage PR2 and Segway RMP.

In the Kinect-based navigation system, proposed by D. Sales et al [1] they used the Pioneer P3-AT robot as the base of the robot and Kinect sensor as the 3D vision sensor. An extra power source (12 V, 2.67A) is needed in order to satisfy the power requirement for the Kinect sensor. In addition, Kinect needs its own USB converter to connect with a computer. Altogether, the robot has to carry extra weight (cables, USB convertor, and battery pack) when implemented with a Kinect sensor. Further, the Pioneer P3-AT robot base is more expensive compared to other available bases such as iRobot Create 2. Also, their system is based on a finite state machine (FSM) for an indoor navigation task. Here, the robot cannot do localization during the navigation. In our proposed system, we used Simultaneous Localization and Mapping [10] (SLAM) algorithm for building the map and localization during the navigation.

The Pioneer robots are a standard in a lot of university research. It is mostly an indoor platform that comes with a sonar ring and a set of optional packages (sensors, pan-tilt, computers, etc.) that can be added. It is approximately about 10” tall and 11” diameter. Research work by Safdar Zaman et al [11] describes how a Robotic Operating System (ROS) based control system is used with a Pioneer 3-DX robot for indoor mapping, localization, and autonomous navigation. The Pioneer 3-DX robot was one of the most popular research robots. Because of its modest and balanced size combined with reasonable hardware, it is most suitable for indoor navigation. Pioneer 3-DX robots use a differential drive for locomotion. In their system a Linux (Ubuntu 10.4) based computer system equipped with ROS was used to control the robot.

The Create is a small and low-cost platform for testing indoor robotic applications. It is about 12” diameter and 4” tall. Several types of research has been carried out using this platform. We have used version 2 in our previous research [12] of making an office assistant robot. The major attractiveness of this platform is that it is inexpensive and easily programmable. Further, it is compatible with ROS.

C. Structure of the base

The basement of the structure is made out of a 5mm thick, 12” wide and 24” long acrylic sheet. This can be considered as a plate in which the vision sensor, circuit boards, and battery pack are mounted on top. And motor wheels and caster wheels for support are at the bottom. Wheels have an 80 mm diameter in each. On top of the plate, the vision sensor is connected to the Raspberry Pi board using a USB cable and powered by the same USB from the same board. On the other hand, Raspberry Pi is powered using a buck converter that is paired with the battery pack. This board is further connected with the Arduino board that helps to control the wheels through a motor shield. Our robot base is a differential type, so the motors are positioned on the same axis. All these components are fixed to the plate using metal brackets, nuts and bolts. The design of the robot is shown in Fig. 1.

D. Hardware and Software

The main controller is the Raspberry Pi 3 Model B+ running Ubuntu 16.04 Mate and ROS Kinetic. The Raspberry Pi controller communicates with the outside computer through WiFi. The computer uses Secure Shell (*ssh*) to give commands to the robot. The ROS program carries out odometry calculation, navigation planning, and mapping using the ROS Kinetic. The Raspberry Pi sends the velocity command to an Arduino which controls the two motors with a Proportional–Integral–Derivative (PID) controller through an Adafruit Motor Shield. It reads the value of the encoder, calculates the speed of each motor and sends back the value to the Raspberry for odometry calculation. Arduino and Raspberry Pi are connected via USB and the Arduino program acts as a ROS node.

ASUS Xtion PRO LIVE sensor was part of the research from the start, as we wanted to do SLAM (Simultaneous Localization And Mapping) but without wasting a lot of money on a lidar. An ASUS Xtion PRO LIVE sensor is basically a 3D-camera and, in addition to the depth scanning needed for

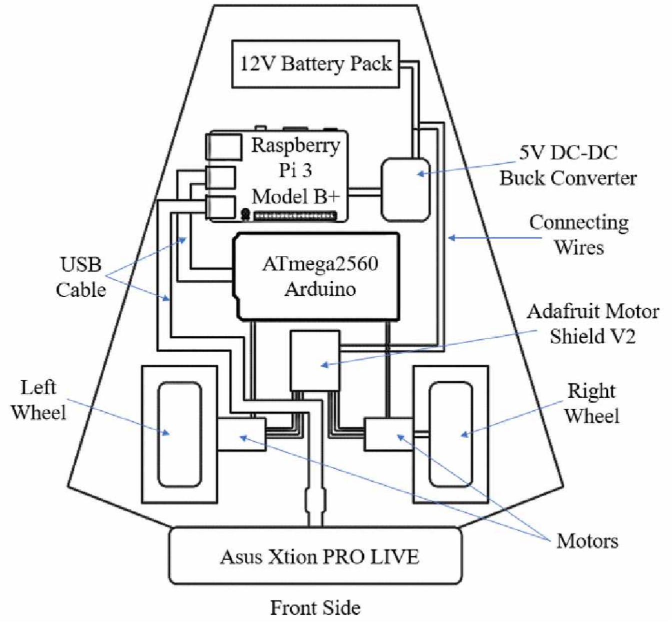


Fig. 1. Top view of robot base design

SLAM, can be also used for computer vision. All of which are handy for the further steps of the study.

5V/10A DC-DC Buck Converter is used to convert the voltage. The motors are running directly with the battery voltage (12V). The Raspberry Pi, Arduino, and encoders are running on 5V converted from the battery.

In the Arduino side, motor control is done through Pulse Width Modulation (PWM). A PID is supposed to manage each motor speed but as the PWM/motor speed ratio is very linear we observe good results with the direct command of the speed and deactivated the PID for now.

E. Mapping and Path Planning

Concerning the path planning, we used the Dynamic Window Approach (DWA) local planner, as it gives the best result for differential drive robots. The surfing for a while, and especially the map starts to get confused a. The fusion of the odometry from the encoder with an Inertial Measurement Unit (IMU) can solve this problem.

In order to get the best odometry, some calibration was done. Basically the robot was driven in a straight line, measured the distance from the starting point manually and compared it with the odometry distance. With the difference between the two, a scale was computed to correct the odometry measure. The same thing was done for the rotation by rotating the robot on its own and comparing the odometry with reality.

F. SLAM Algorithm

Here SLAM algorithm is included in the implementation of the gmapping node. SLAM algorithm was introduced by J. J. Leonard and H. F. Durrant-Whyte as an application of the extended Kalman filter (EKF). They developed an algorithm for model-based localization that relies on the concept of a geometric beacon a naturally occurring environment feature that can be reliably observed in successive sensor measurements and can be accurately described in terms of a concise geometric parameterization. The Kalman filter relies on two models: a plant model and a measurement model. The plant model describes how the vehicle's position $x(k)$ changes with time in response to a control input $u(k)$ and a noise disturbance $v(k)$.

$$x(k+1) = F(x(k), u(k)) + v(k), \qquad v(k) \sim N(0, Q(k))$$

Where $F(x(k), u(k))$ is the nonlinear state transition function. the used the notation $u(k) \sim N(0, Q(k))$ to indicate that this noise source is assumed to be zero-mean Gaussian with variance Q(k). The measurement model expresses a sensor observation in terms of the vehicle position and the geometry of the beacon being observed and has the form,

$$z_{\mathrm{j}}(k) = h_{\mathrm{i}}(p_{\mathrm{i}}, x(k)) + w_{\mathrm{j}}(k), \qquad w_{\mathrm{j}}(k) \sim N(0, R_{\mathrm{j}}(k))$$

The observation function $h_i(p_i, x(k))$ expresses an observed measurement $z_j(k)$ as a function of the vehicle location x(k) and beacon location p_i. This observation is assumed corrupted by a zero-mean Gaussian noise disturbance $w_j(k)$ with variance $R_j(k)$. The form of the observation function $h_i(.,.)$ depends on the sensor employed and the type of beacon being observed. The goal of the cyclic computation is to produce an estimate of the location of the robot $\hat{x}(k+1 \mid k+1)$ (The term $\hat{x}(i \mid j)$ should be read as "the estimate of the vector x at time step i given all observations up to time step j") at time step k + 1 based on the estimate of the location $\hat{x}(k \mid k)$ at time step k, the control input u(k) and the new beacon observations $z_j(k + 1)$. The algorithm employs the following steps: prediction, observation, matching, and estimation [12].

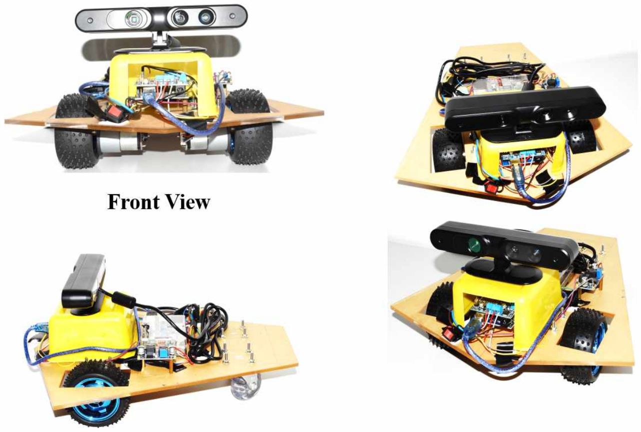
G. 3D Vision Sensors

3D vision sensors provide both RGB image and distance information by creating a RGB-D image: hence, they may be adopted to identify natural landmarks while measuring their relative position. Therefore, they are known as RGB-D sensors. Over the past 10 years a large number of RGB-D sensors have been developed by the several companies, such as the Microsoft® Kinect V1 [13], Primesense™ Carmine [14], Asus Xtion Pro Live [15], Microsoft Kinect V2 [16], [17] and Intel® Realsense [18] etc.

III. RESULTS AND DISCUSSION

In this research, we implemented a wheeled robot base that can autonomously navigate in an indoor environment. This robot weight 1.5 kg. Its length is 35 cm and width is 30 cm. The base can handle up to 5kg of the total load. Based on the wheels used, the robot base can move in rough flat surfaces.

We have considered three main aspects to choose materials and tools for robot making. Those are cost, efficiency, and durability, especially when selecting the 3D vision sensor. We found out that most of the researches have been conducted using Microsoft Kinect Sensor Version 1.0. The device weight is large compared to other similar sensors available in the



Front View

Side View

Top Views

Fig. 2. Structure of Autonomously Guided Differential Drive Robot Base

Fig. 3. Local map of the unstructured laboratory area

TABLE I
EXPERIMENTAL RESULTS FOR AUTONOMOUS NAVIGATION OF THE ROBOT BASE

Location	Successful attempts (out of 50)	Percentage (%)
Location A	48	96.0
Location B	47	94.0
Location C	45	90.0
Location D	49	98.0
Location E	42	84.0
TextAccuracy of Autolooms Navigation		**92.4**

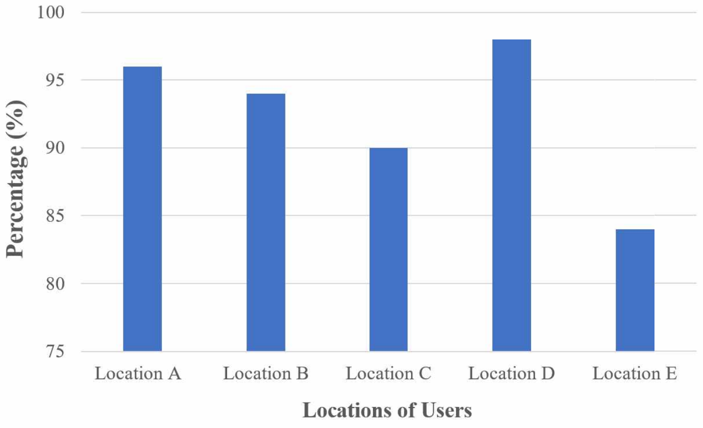


Fig. 4. System performance in unstructured indoor environment

market as stated in the literature review. We have selected Asus Xtion Pro sensor is a lightweight low cost and also, it has an attractive appearance [19].

After assembling all the components of the base as shown in Fig. 2, we performed a test to verify the accuracy of goal acquisition of the robot. The testing environment was an unstructured laboratory of dimension 5.7m × 5.6m × 3.3m. We have trained the robot for the environment and obtained the map of the unstructured laboratory area (See Fig. 3) for the autonomous navigation. After that, five places inside the laboratory were defined as goal locations. Rviz, the visualization tool for ROS, has the *2D nav goal* function which we used for giving random goals to the robot. We tested the robot navigation for 50 times per location, 250 times in total. However, it was successful 231 times only. Overall, the robot base performed 92% accuracy. The results for each location are listed in the TABLE I. Similarly, a graphical representation of results are shown in the graph below (see Fig. 4).

The developed robot base will be further improved in the near future by connecting a robot arm on top of the base. Finally, we hope to implement a robot having an arm for storage handling in an indoor office environment.

IV. CONCLUSIONS

We have built an autonomous robot base having two hardware units. A separate processing unit and a movable robot structure were used in advance. These two components comprised of ROS kinetic, Asus Xtion Pro, Arduino and Raspberry Pi that communicated in between. The robot communicates with the central location PC through a Private Wi-Fi connection. Our robot was implemented and initially tested in an unstructured indoor environment. The results prove that the implemented structure has high accuracy in perceiving the environment and it can be successfully used in an unstructured environment. Ultimately, the robot will help to make user's storage keeping tasks easier.

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