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Design and Implementation of Robust Navigation System Platform for Autonomous Mobile Robot

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***Abstract*: An autonomous robot can navigate in a given region and reach to a specified location. The navigation system for these robots has to be reliable, versatile and rugged. In this paper, design and development aspects of such navigation system are discussed. A two level architecture is proposed for navigation of the autonomous robot. The low level controller (LLC) generates odometry data and implements closed loop feedback based PID algorithm. The high level controller (HLC) is used to generate velocity commands based on the path planned and inputs sensed from environment. The two controllers continuously exchange data with each other to reach the final destination. This navigation system platform can be used to develop autonomous mobile robots.**

***Keywords*: Autonomous Mobile Robot, PID, Odometry, Robotic Operating System (ROS), High Level Controller (HLC), Low Level Controller (LLC).**

I. INTRODUCTION

Autonomous robot navigation has attracted attention of many researchers in the areas of robotics and autonomous systems. The robot is required to reach a specified location in an known or unknown environment [1]. There are number of challenges while designing the navigation system which include unknown and dynamic environment, limitations due to sensor capabilities and lack of efficient navigation algorithm. Moreover these robots are used for different applications hence the design has to be application specific. For example, an autonomous beach cleaning robot design is discussed in [2]. There are number of other applications of robot navigation like manufacturing automation, explosive detection, automation in malls etc. Our aim is to design and develop a navigation system platform which can be utilized in any autonomous robotic application. This will make the development of autonomous mobile robots faster and cheaper. For design of navigation system platform we need to have appropriate control systems. Such control systems are supposed to have control algorithms that will make mobile robots successfully moving over a rugged surface, avoid obstacles, follow a path as a coordinates given by a user. In this paper the design and simulation of reliable and robust navigation system for autonomous mobile robots is proposed. The navigation system described here is a part of general purpose mobile platform to be developed.

The rest of the paper is organized as follows. Section II gives related work in this area. Section III describes detailed architecture of the autonomous mobile robot. Section IV gives details about navigation system. Section V has discussion on implantation and testing. Finally section VI gives conclusion and future scope.

II. RELATED WORK

The navigation problem involves various subtasks such as path planning, collision detection, search algorithms, environment representation etc. A detailed review of these aspects and research challenges is given in [3]. Navigation system can be implemented for known or unknown environment. The latter is more challenging. The early navigation systems for intelligent mobile robots [4] used ultrasonic range sensors. Experimental study of outdoor navigation system using GPS is presented in [5]. Researchers also have attempted to replicate navigation of a robot in cyber world to real world [6]. Implementation and testing of localization and navigation of indoor mobile robot is discussed in [7]. Several control algorithms for autonomous navigation are available in literature. One such simple algorithms using PID controller can be found in [8].

III. SYSTEM ARCHITECTURE

A mobile robot consists of an on board computer or microcontroller to perform various operations related to navigation of the mobile robot. It collects data from different sensors connected to it. There are two motors mounted with rotary encoders for differential drive robot. They are used to measure rpm of the motors which helps in calculating distance travelled by the mobile robot. A two level architecture is used to collect information of the current position of the robot and surrounding environment. The HLC is interfaced with Inertial Measurement Unit (IMU), 2D laser and the user device.

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IMU collects the directional values which are used to measure angular displacement and orientation of the mobile robot.The calculated distance & angle together is used to localize the mobile robot & further navigate to its next location.
Fig. 1 shows the block diagram of the autonomous mobile robot.

The LLC is used to calculate the distance travelled by the robot, its current speed and its current position w.r.t. initial position. It also generates suitable signals to achieve desired speed and direction.

The HLC and LLC continuously exchange information in order to traverse the desired path and reach the final destination.

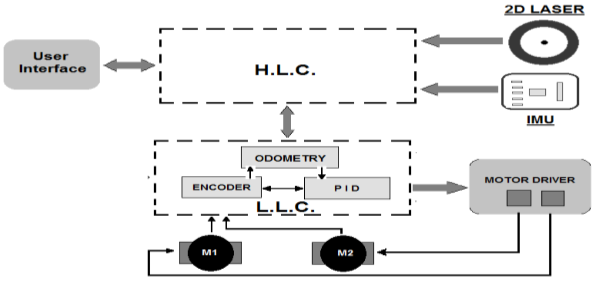

Fig. 1.System block diagram (Architecture)

IV. LOW LEVEL CONTROLLER & NAVIGATION SYSTEM

Nanigation of robot is the abiliyt of robot to determine its own position in its frame of reference and then to plan its path towards some predecided goal location. In order to navigate in its environment, the robot or any other mobility device requires representation, i.e. a map of the environment and the ability to interpret that representation.

At lowest level of Self Navigating robots, a linear navigation system is implemented to traverse two closest points on plane linearly. These points when taken as collection seems to make a curvilinear path suitable for efficient navigation of Robot.

The linear navigating robot moves along any one direction in a straight line with a desired speed. Differential Drive robot has ability to rotate in desired direction and attain desirable speed by changing the speed of both motors differentially, thereby attaining desired curves with suitable speed of turning.
Distance travelled by the wheels can be calculated in terms of electronic pulses given by the encoders attached to the motors. There are following challenges which need to be tackled.

i) Inaccuracy in speed measurement
ii) Sideways motion
iii) Inaccurate distance traversal by robot due to missed encoder counts

Encoder mechanisms of motors give fixed no of pulses per rotation. We need to read and store these electronic pulses and map it into the distance travelled.

A. Distance Calculation

For precise detection of distance with the direction of motion, we found that one needs to check for the specific sequence of bits instead of checking for a single encoder pulse. To achieve this, we attached hardware interrupt on both the encoder pins and assigned the name LSB and MSB respectively. A sequence of 4-bits is created by shifting the previous bits to the left and adding the latest bit at LSB. This generates 8 different 4-bit sequences for clockwise and anticlockwise motion of wheels. Algorithm 1 gives detailed steps.

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Algorithm 1 : Distance Calculation

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1. Set MSB to Encoder Pin 1
2. Set LSB to Encoder Pin 2
3. Create Encoded Sequence using shift and add
4. If resultant sequence is equal to (1101,0100,0010,1011) Increase the encoder value.
5. If resultant sequence is equal to (1110,0111,0001,1000) Decrease the encoder value.

The encoder value describes the distance travelled by the wheels. The above algorithm works well for all conditions of navigation without fail or without missing any count.

B. Speed Calculation

For real time & precise speed calculation of each motor, timer interrupt has been used. The interrupt will be generated at a fixed interval of time(generally microseconds intervals) and it will call the speed calculation subroutine for each motor.

The change in encoder ticks per period will be the instantaneous speed. This speed in Ticks per interval will be converted into standard unit(meters per seconds) while interfacing with high level controller.

C. Odometry

Odometry is the powerful mathematical tool for localization of robot in space. Based on previous position and encoder data, odometry helps robot to determine the current position of robot relative to the initial position. Difference in travelled distance by both wheels(Say DistanceA & Distance B) will give us change in heading angle of the robot (say Angle). The contineous integration of these angle differences will give us orientation of Robot with refence to its initial orientation (say Yaw). The final positions of the robot (say X and Y) are calculated using distance and final heading angle Yaw. Algorithm 2 describes the procedure.

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Algorithm 2 :Position Estimation

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1. Diff = DistanceA - DistanceB
2. Centre_dist = (DistanceA+DistanceB)/2
3. Angle=(Diff/Width)
4. Yaw +=Angle
5. X=X+(Centre_dist*cos(Yaw))
6. Y=Y+(Centre_dist*cos(Yaw))

In order to validate the above presented concepts on control of autonomous robots, we performed several tasks and verified the algorithms.
In order to get precision of highest level, we used high PPR encoder motors and implemented the 4-bit sequence matching on pulses returned by encoder motors.

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D. Velocity Inputs

High level controller generates the velocity input as per planned path for the robot which should be followed precisely by Low level Controller.

This velocity w.r.t. to center of rotation must be resolved according to the robot model. For differential drive model, this speed needs to be resolved for 2 driving wheels. Following calculations are used to resolve the center velocity into velocities of right & left wheel.

$$V_{left} = V_{linear} - V_{angular} \times \frac{L}{2} \quad (1)$$

$$V_{right} = V_{linear} + V_{angular} \times \frac{L}{2} \quad (2)$$

where,

V_{linear} is linear velocity w.r.t. the robot's point of rotation.

$V_{angular}$ is angular velocity w.r.t. the robot's point of rotation.

L is distance between the driving wheels.

E. PID

The PID controller implements control system algorithms in discrete level. The Robot can take feedback of its velocity by comparing the current velocity and desired velocity determined by path planned by the Robot controller on board. The velocity feedback is given to the PID Controller for generating error correcting PWM signal. This PWM is in turn given to the respective motors for achieving desired velocity. The current speed of the motors is decided by the feedback of PID controller considering the proportional, differential and integral aspects given by Equation 3.

$$u(t) = K_p e(t) + K_I \int_0^t e(\tau)d\tau + K_D \frac{de(t)}{dt} \quad (3)$$

Where, $e(t)$ is difference between desired velocity and current speed of the robot. The PID coefficients K_P, K_I and K_D are tuned manually based on the size & weight of robot and motor specifications.

V. IMPLEMENTATION, TESTING AND RESULTS

Fig. 2 shows the autonomous mobile robot platform with robot base, motors with their drivers, LLC & power supply. The low level controller is implemented using Cortex M3 based microcontroller. The functions of HLC can be simulated using Robot Operating System (ROS). The autonomous mobile robot is interfaced with a PC installed with Robot Operating System (ROS).

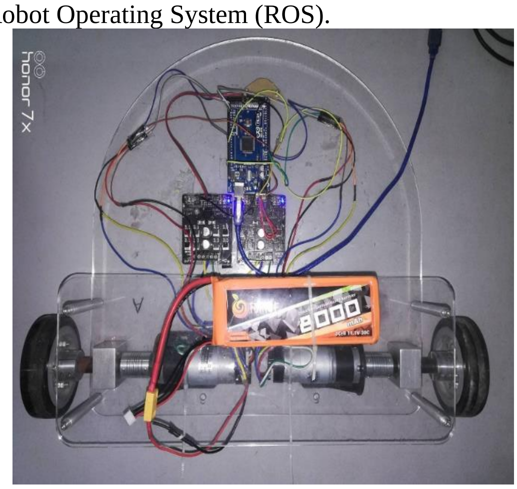

Fig. 2.Autonomous Mobile Robot Platform

ROS is used for implementing Path Planning of the autonomous robot. Being open-source, it contains the work of many Robotics enthusiasts to help with advanced work like Path Planning, Simultaneous localization and Mapping (SLAM) and obstacle avoidance etc. Fig. 3 shows the path planned in ROS Visualization tool based on the final destination and the surrounding map.

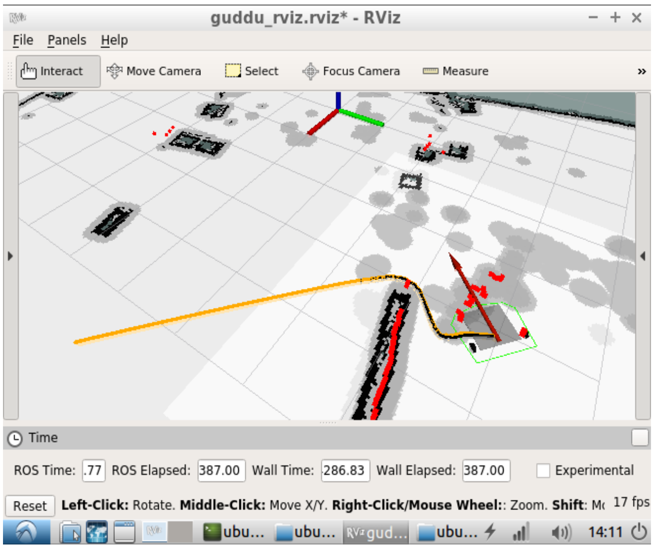

Fig. 3.Autonomous Mobile Robot Platform

ROS System is interfaced with Low level Controller (LLC) serially. It generates the velocity commands for robot based on odometry data of the robot to execute planned path. The LLC sends odometry data consisting of position, velocity and orientation of the robot to HLC i.e ROS.

Table I shows five samples of velocity commands generated by the ROS based HLC and odometry data generated by LLC. It can be seen that the parameters generated by the two controllers are accurate up to 2 decimal places.

Table- I: Data Generated by H.L.C. & L.L.C.

S#	Velocity Commands Generated by ROS (HLC)		Odometry Data Generated by LLC		
	V_{linear} *(m/s)*	$V_{angular}$ *(m/s)*	Position *(m)*	V_{linear} *(m/s)*	$V_{angular}$ *(m/s)*
1	0.270	0.336	(-0.40,1.81)	0.264	0.333
2	0.296	0.302	(-0.38,1.80)	0.286	0.311
3	0.321	0.251	(-0.34,1.72)	0.322	0.260
4	0.349	0.220	(-0.33,1.71)	0.351	0.220
5	0.432	0.214	(-0.27,1.68)	0.422	0.213

The control parameters shown above are continuously exchanged between ROS enabled High Level controller and the Low-level controller to reach the final destination autonomously.

VI. CONCLUSION AND FUTURE SCOPE

In this paper, a two layer design of autonomous robot navigation platform is proposed. A control algorithm is designed which can make the robot follow an arbitrary specified path. The designed control algorithm is found to be robust against various system uncertainties.

The algorithm is implemented and tested successfully in LLC. The interface with ROS based HLC is also tested successfully.
In addition to control algorithm, mobile robot also requires a wide range of capabilities.

These capabilities include position estimation, mapping, fast communication, human interface, multiple client support and monitoring robot status for safety and debugging. Further work can include implementation of these capabilities and hardware implementation of HLC. The autonomous mobile robot platform then can be used to build number of applications.

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