Design of a Cost-Effective Autonomous Holonomic Vehicle for Warehouses

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***Abstract*—Robotics has been advancing throughout the last few decades in the world. However, it has primarily penetrated the market from high-capital companies. This leads to inferior penetration in lower capital companies and organizations like local warehouses and businesses. The primary reasons for this are the high initial cost, high maintenance cost, and difficulty accessing these robots and understanding them. This paper aims to provide the design and implementation of an automated holonomic robot with a focus on cost-effectiveness that performs path tracing along with a path planning interface for ease of access. It aims to provide a productive system that aids the warehouse sector in reducing human reliance on manual path planning, minimizing necessary effort, saving time, and providing a smooth path trajectory.**

Keywords—robotics, holonomic, path-planning, path-tracing, interface, low-cost

I. Introduction

Developing countries such as India have been adopting robotics solutions for warehouse automation in recent times. However, this integration is limited to companies and organizations that have the necessary capital to bring in the resources required to build these robotic systems, hire the engineers to maintain them, and time to gain the knowledge to adapt these systems to their own. Low-capital local businesses and warehouses thus tend to stray away from adapting robotics systems into their warehouse, thus limiting the reach of robotics to only those organizations that have the time and capital to invest in such systems. Robotics face the following difficulties in India and other developing nations:

- It is an expert-oriented field that requires enormous capital to start.
- Requires a huge background of prior knowledge and experience in the field.
- Experts need to be hired to provide maintenance and programming support.

Thus, Warehouses continue to face a significant bottleneck due to a lack of human efficacy and poor management. The project aims to combine cost-effectiveness and ease of access to streamline a smart and effective machine that boosts the productivity of individual warehouse operations. It proposes a 2 stage system - an automated bot to execute path tracing and an interface to implement path planning.

II. Methodology

The major components involved in the design of this robot are as follows:

- Drive Structure and Frame
- Electronics Architecture
- Programming Algorithms
- User Interface

The aim in the design of the first three components was to reduce costs while still providing relatively the same performance. This slight loss in performance is justified by its use case in small operations for lower capital companies where performance metrics like speed, positional accuracy, repeatability don't necessarily hold the same importance as in large scale warehouse operations. Much of the appeal of the customizability available in high-end warehouse automation solutions thus becomes a disadvantage in the use case for which this system is to be deployed as it creates a barrier of understanding. Hence, the 4th component is designed in a way to improve the ease of access, by removing hard to understand customizable options, and instead opts for using simple algorithms to automatically estimate optimum values for these. The design of these components is described below.

A. Drive Structure

The mechanical structure and base frame of the robot mainly consists of Aluminium (1060 alloy) box sections, Stainless Steel laser-cuts and 3D printed ABS parts. This keeps the costs to a minimum while still providing the necessary structural integrity.

There are various drives that can be adopted to create a warehouse automation robot, a comparison of the most commonly adopted ones is given below.

TABLE I. Comparison of Drives

Table Head	*Tank*	*Omni*	*Mecanum*	*Swerve*
Holonomic	No	Yes	Yes	Yes
Max Speed	High	Medium	Low	Medium
Max Acceleration	High	Low	Medium	High

Table Head	*Tank*	*Omni*	*Mecanum*	*Swerve*
Complexity	Low	Medium	Medium	High
Cost	Low	Low	Medium	High

The calculation for maximum speed and acceleration was performed by modifying the method provided in [1]. The approach specifies a way to calculate the required torque for a particular acceleration given the weight, coefficient of rolling friction and other factors.

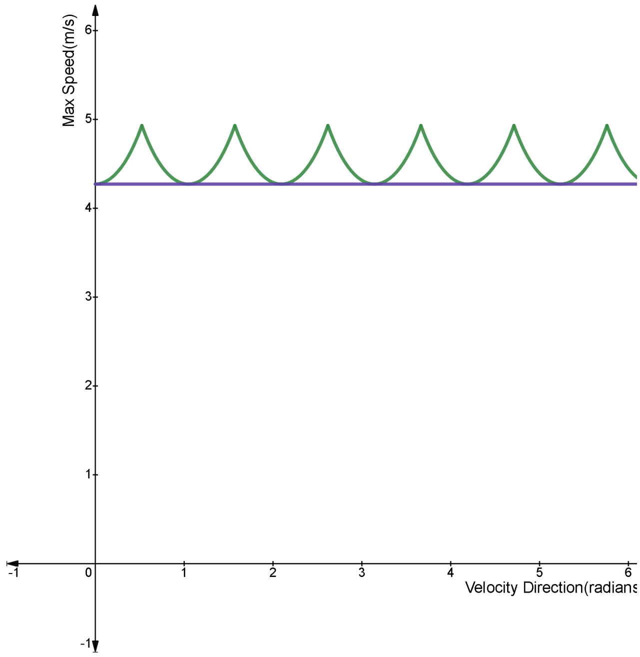


Fig. 1. Comparison of Omni vs Swerve (Velocity)

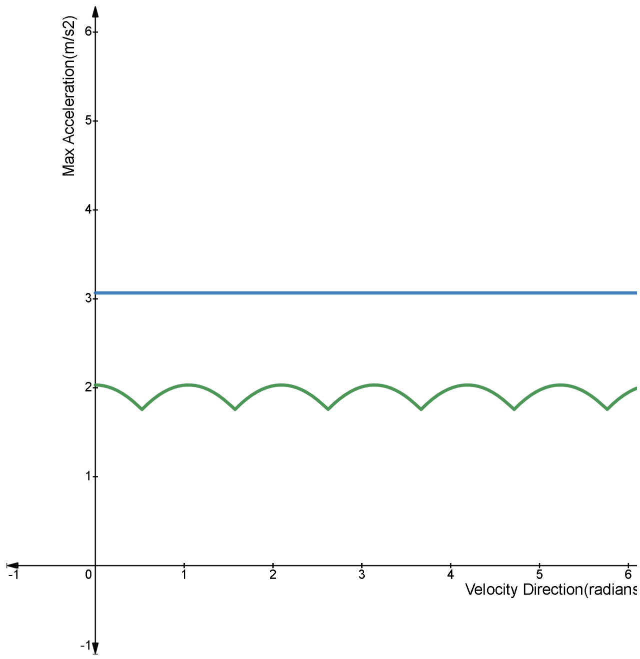


Fig. 2. Comparison of Omni vs Swerve (Acceleration)

From the above data it is clear that a 3-wheel Omni drive would be the optimal way to create a cost-effective holonomic robot.

B. Omni *Working*

1) Omni wheels are wheels with small discs (called rollers) around the circumference which are perpendicular to the turning direction. These wheels are often employed in holonomic drive systems.

2) The effect is that the wheel can be driven with full force, but will also slide laterally with great ease.

3) The effect is that the wheel can be driven with full force, but will also slide laterally with great ease.

4) Usually, this is achieved by using an H-drive. .

C. Components Of PID

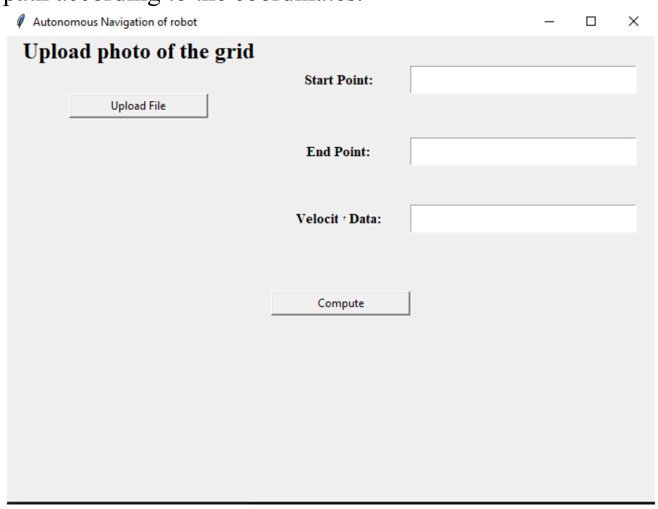
1) Proportional tuning involves correcting a target proportional to the difference. Thus, the target value is never achieved because as the difference approaches zero, so too does the applied correction.

2) Integral tuning attempts to remedy this by effectively cumulating the error result from the "P" action to increase the correction factor. For example, if the oven remained below temperature, “I” would act to increase the head delivered. However, rather than stop heating when the target is reached, "I" attempts to drive the cumulative error to zero, resulting in an overshoot.

3) Derivative tuning attempts to minimize this overshoot by slowing the correction factor applied as the target is approached.

D. User Interface

We used python’s tkinter library to build the user interface. It provides the facility to upload the warehouse’s top view image and then enter the start point and end point. The compute button gives us the path according to the coordinates.



1) A Algorithm*

The A* Search Technique is a straightforward and effective search algorithm that may be used to identify the best route connecting two nodes in a graph. It will be put to use in order to find the shortest way. This algorithm is an expansion of Dijkstra's Shortest Path Algorithm. The change in this case is that heaps (binary trees) are used to hold all the elements rather than a priority queue. The A* Search Algorithm additionally makes use of a heuristic function that offers additional details about how distant we are from the objective node. To increase the effectiveness of searching, this function is combined with the f-heap data structure.

III. Results

The study mentions the robot's mobility with a constant orientation across all conditions, providing incredibly good control over the robot's navigation. The motion planning techniques covered in this article are applicable to all of these applications. Therefore, the time will soon come when robots will help with household chores as well as moving items within businesses, delivering supplies between rooms in hospitals, and other tasks. In comparison to the other controllers, the Linear Model Predictive Controller was more suited for path tracking applications. However, we observed that the computational power was a factor in the linear model predictive controller's performance.We intend to use our autonomous bot to test these methods in further works, and we also intend to use dynamic models to develop the controller in higher-speed scenarios. The feedback controller's efficiency and speed are demonstrated by comparing the performances of closed-loop systems with the given controller with a typical human driver.

Thus, the robot's total price came to Rs. 4,95,636. The bot's own functionality, accuracy, stability, and precision justify its price. However, switching from a DC drive system to a BLDC drive system can dramatically save costs, as demonstrated in the research articles cited above. This accounts for over 43% of the decline. By converting from a 3 wheel to a 2 wheel odometry system, more reductions can be achieved. Another strategy is to replace an expensive AHRS with a cheap IMU and upgrade its algorithm. Although this produces less-than-ideal results compared to AHRS, it offers superior cost savingsThe cost of materials decreases to Rs. 2,02,708 due to the new system architecture and control system adjustments. The reduction here is about 59%. However, there are other drawbacks to this. Both implementing and fine-tuning the system are challenging tasks. To compensate for the accuracy loss, numerous algorithms must be used.

Because A* will produce the solution more quickly than Dijkstra, we choose it over the latter approach. Due to the heuristic value that was included in the computation, A* scans the region solely in the direction of the target, whereas Dijkstra searches by stretching out equally in all directions and typically ends up examining a considerably greater area before the target is discovered, making it slower than A*.

Sr. No.	**RESOURCES REQUIRED**	**Specifications**	**DESCRIPTION**	**AMOUNT**
1.	Cytron (Veddar's Electronic Speed Controller) x3	Voltage Rating- 24V	DC motor driver.	Rs.8,487/-
2.	IMU (Inertial Measurement Unit) Sparton AHRS-8P	9 axis IMU	Using an accelerometer, magnetometer, and gyrometer it will give us yaw which we will use for the navigation of our robot.	Rs.1,10,000/-
3.	TM4C123GH6PGE Microcontroller) x3	Clock Frequency - 80Mhz Operating Voltage-3V3 Communication Protocols-CAN, USART, SPI, I2C Floating Calculation - FPU NVIC	It will collect data from IMU , Sensors and other peripherals and compute the data to perform the required task.	Rs.4,590/- +custom duty
4.	Printed Circuit Boards	2-4 Layer PCB Surface finish - HAL(sn-pb) Temperature Gradient-std.Tg(130-140 degree)	We plan to build our own PCBs as per the requirements. This will make our other processes easy and modular.	Rs 10,000
5.	PS4 Controller	Dualshock 4 Wireless Controller	It will be used to remotely control the robot.	Rs. 4,559/-
6.	Batteries (lipo and li-on)	lipo(24v,5000mAh,40C) lion(8v,3500mAh,3C)	It will be used for the power supply of our robot.	Rs.8,000/-
7.	Resistors, capacitors, leds, op-IC	Resistors-1/10 W Capacitors-30V (voltage rating)	Required for our designed circuits.	Rs.10,000/-
8.	Autonics Encoder x6	Resolution - 500CPR Operating Voltage - 5v	By applying inverse kinematics in the omni equation ,we will be using it for localization.	Rs.30,000/-
9.	Maxon RE40 with 1:12.25 Gearbox x3	Operating Voltage - 24V	We will be using it in the base drive for navigation.	Rs.240,000/-
10.	Raw Material	Fasteners, 3D print Filament, Alu Extrusion ,SS Ex., CF Ex., MS Ex., ABS Blocks,Sheet Metal, ALU 6061 Alloy Blocks,	Will be used as consumables	Rs.70,000/-

Limitations

[1] A* algorithm requires a heuristic function to work, and calculating this function is difficult if we wish to optimize the algorithm.

[2] This approach takes wheel slippage into account during odometry but not during drive kinematics.

[3] The main problem with 3 wheel odometry is its price. The approach is more difficult to install and consumes 1.5 times as much resources. Making sure that the three wheels are all 120 degrees apart from one another is more difficult. The calculation is flawed because of this inherent inaccuracy.

[4] Enhance the control algorithm and take more into account centroid location changes brought on by variations in vehicle quality. In order to confirm the timeliness of the algorithm developed in this research, we also need to test it on a test bench and an actual vehicle.

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