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Design and Implementation of an Autonomous Robot for Safe and Efficient Food Delivery in Hospitals

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ABSTRACT

In recent years, the demand for autonomous robots in healthcare settings has increased, particularly after the COVID-19 pandemic. Traditional methods of food delivery in hospitals, requiring staff to transport meals to patients' rooms manually, can be dangerous in isolated hospitals where people infected with highly contagious diseases are treated. This paper details the design and virtual implementation of Transbot, a robot that acts as an intervening medium between doctors and patients infected with communicable diseases. It can autonomously navigate to any required location while simultaneously recognizing and avoiding obstacles, ensuring safe and efficient delivery of meals to patients' rooms. It is also equipped with the Rocker Bogie mechanism, allowing it to navigate between floors of a hospital with ease.

Keywords - *Covid-19, Autonomous Navigation, SLAM, Food delivery, Rocker-Bogie Mechanism.*

1. Introduction

The COVID-19 pandemic has led to an increased need for isolation facilities in hospitals to prevent the spread of the virus. In these facilities, patients are isolated from the general population, and hospital staff must take extra precautions when entering and leaving patient rooms to prevent the spread of the virus. Moreover, traditional methods of food delivery in isolation facilities can be risky, requiring staff to wear personal protective equipment (PPE) and take extra precautions when entering patient rooms. This not only increases the workload for hospital staff but can also lead to potential exposure to the virus. Autonomous robots can assist in the delivery of food and medicine.

The paper is organized as follows: in section 2, we provide a detailed literature review. In section 3, we discuss the design of linkages of the Rocker-Bogie Suspension & the two iterations of Transbot. Section 4 presents the process of autonomous navigation & the results of our testing and evaluation of the robot's performance, including its ability to navigate the isolation facility and deliver meals in a safe and efficient manner. Section 5 shows the 3D models. Finally, we conclude the paper in section 6, discussing the contributions of our work, limitations, and future directions for research.

2. Literature Review

The purpose of this literature review is to examine and evaluate the existing research on the usage of autonomous robots for delivering food in hospitals. Several papers pertaining to this were consulted and some that were particularly useful are summarized and listed.

Stair-climbing robots can make use of the Rocker-Bogie suspension mechanism which was first developed by the NASA Jet Propulsion Laboratory for the Mars Pathfinder mission in 1996. It consists of rocker arms and bogie assemblies that enable the robot to traverse rough terrain while maintaining stability. The dimensions of these linkages must be carefully determined. These research papers provided insight into the rules that must be followed so that the robot climbs stairs with high stability. They are:

1) Having only one pair of wheels in the rising position at any given time.
2) Having the third pair of wheels at the top of the stair before the first pair of wheels start climbing the next stair.
3) Having all the wheels remain in contact with the ground even when traversing obstacles or negotiating steep inclines to prevent the robot from toppling over [1], [2].

Since the robot stays in close proximity to infected patients, it is crucial to disinfect the robot itself. Surface contamination by bacteria and viruses has been found to be one of the leading reasons for the spread of the virus. Hence, the choice of the right material is of huge importance. It is indicated by the Centre for Disease

Control and Prevention (CDC) that the three main mechanisms of virus transmission are the spread of infectious droplets through:

1) Airborne
2) Person-to-person
3) Surface contact

We found that research exists supporting the role of copper surfaces as an antimicrobial material. A correlation is found between the increase in copper content and the increased contact-killing of bacteria. Concerning Coronavirus, it remains infectious for at least 5 days on common surface materials, including polytetrafluoroethylene (Teflon), polyvinyl chloride (PVC), glass, silicone rubber, ceramic tiles, and stainless steel. Exposure to copper destroys the virus and its ability to self-replicate. Copper Nickel Alloys were also effective at inactivating Coronavirus but required higher i.e., 90 percent copper content. Alloys containing more than 90 percent copper inactivated 1000 PFU (Plaque-Forming Unit). To facilitate the use of existing parts, the cold-spray technique can be used to apply copper coatings quickly [3], [4], [5], [6].

To further minimize contact, robots can be automated so that they can function without any human intervention. Simultaneous Localization and Mapping, commonly known as SLAM, is a computational process used in robotics to build maps of different environments. This allows us to simultaneously determine the location of the robot on the map. SLAM algorithms use sensors like cameras, laser-emitting devices, and sonars to capture data about the surroundings and then utilize that data to generate a map. This map is then used to calculate the robot's current position in the environment. When the robot is given a target destination, the SLAM algorithm utilizes the previously generated map to find the shortest path. However, when dynamic obstacles are encountered, the laser sensor scans the map and updates it accordingly. This paper highlights the creation of an environment and its mapping with the RViz (ROS Visualization) simulator, with obstacles added to test the robot's pathfinding abilities. The results show that the robot's response time is satisfactory, and it takes a reasonable amount of time to reach its destination [7], [8].

2D LiDAR (Light Detection and Ranging) is a sensor that's widely used to capture data from the surroundings. The LiDAR emits laser pulses, which strike objects in the surroundings. When these pulses travel back to the lidar, it calculates the distance to the obstacle from the current position [9], [10], [11].

3. Design Calculations

3.1. Staircase Dimensioning

The two-dimensional design of the linkages forms the core of getting the mechanism to work properly. If the lengths and angles aren't proper, the robot may not be able to climb stairs. The lengths and angles of the linkages can be changed as per requirements. In order to determine the length, the dimensions of the stairs, i.e., the width and the height, that the robot will have to climb have to be determined. The

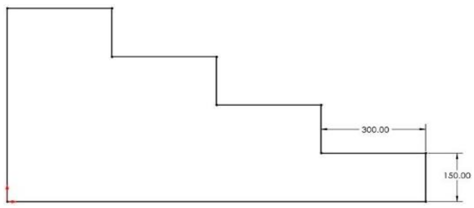

Fig. 1. Staircase dimensions

dimensions chosen can be seen in Fig. 1.

3.2. Linkage Design

Iteration 1

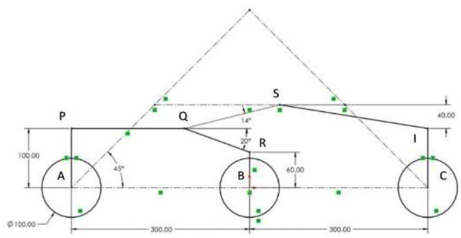

Fig. 2. Sketch of iteration 1

For designing the linkages, we used the Isosceles triangle method to determine the dimensions of the links. Points A, B, and C represent the position of the wheels. These wheels are equidistant from each other. The rocker-bogie suspension mechanism consists of a rocker link and a bogie link. The rocker link is represented by Q-S-I-C and the bogie link is represented by A-P-Q-R-B. Here, point S represents the position of the shoulder joint, where the box will be attached to carry the load. Q is the point where the rocker and bogie linkages would be connected.

Iteration 2

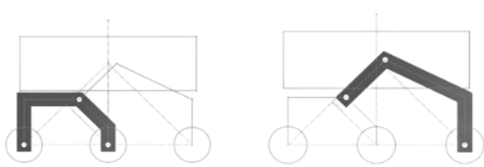

Fig. 3. Iteration 1 linkages

The following significant changes were incorporated:

1) Mild Steel plates were replaced by PVC pipes for the linkages. Implementing this change reduced the weight of the robot significantly.
2) In iteration 1, the wheel distance between points B and C was more. This resulted in two pairs of wheels climbing simultaneously. This distance has been reduced.

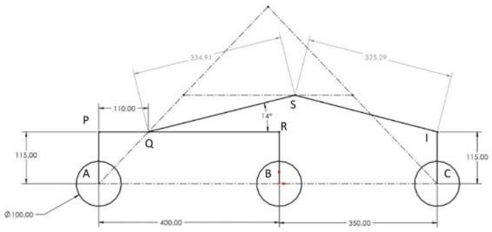

Fig. 4. Sketch of iteration 2

Simulation

Algodoo software (a physics simulation tool that can be used for 2D simulation), was used in order to ensure that the robot's motion is as desired. It enabled us to analyze the system w.r.t. the following points:

1) The ground clearance should be such that the box shouldn't collide with the stairs.
2) Only one pair of wheels should be climbing stairs and the other two pairs should be in contact with the ground.
3) The location of the center of gravity must be low for maximum stability i.e., to avoid toppling while climbing stairs.

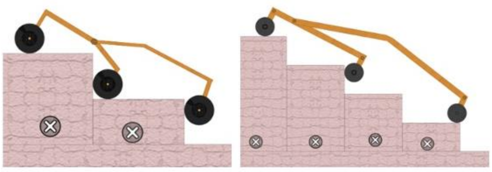

Fig. 5. Sketch of iteration 2

As seen from the simulation, Iteration 2 allows only one pair of wheels to climb the stairs while the other two pairs stay in contact with the horizontal. This is an important design constraint when designing a rocker-bogie mechanism, as mentioned previously.

4. Autonomous Navigation

Automation is the ultimate method to reduce contact between doctors and patients infected with contagious diseases. Autonomous robots are particularly useful in isolation hospitals, where people infected with extremely contagious diseases are treated.

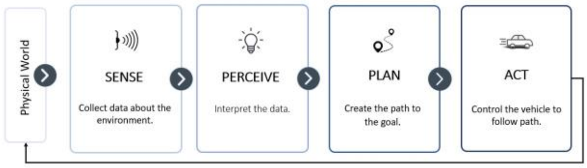

Fig. 6. Automation process

-Physical World:
It refers to the environment in which the robot is present in. It not only includes the static obstacles such as civil structures, hospital trays and other stationary equipment, but also dynamic obstacles such as moving people, other robots, etc.

-Sense:
It includes collecting data about the environment, such as gauging the locations of objects, sensing the nature of these obstacles, etc.

-Perceive:
It involves interpreting the data received, such as measuring and calculating distances of the obstacles from the robot's current position.

-Plan:
It involves planning the courses of action to be taken to deal with the situation.

-Act:
It refers to sending signals to actuators to perform the planned activity. Examples of this include increasing/decreasing the RPM of wheels, stopping the wheels of one side while turning.

Robot Operating System (ROS)
ROS is not an actual operating system, but rather a collection of tools and libraries specifically designed to build robots. It runs on Ubuntu. ROS includes following modules shown in Fig.7

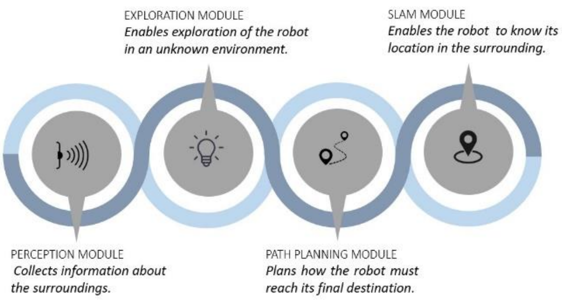

Fig. 7. Overview of ROS

Process

1) Installation of Linux and Ubuntu 20.04.
2) Installation of ROS Noetic.
3) Installation of the libraries and packages (catkin_ws (workspace), Differential Drive, Lidar, gmapping, slam, map saver.)
   - Catkin_ws: A directory designated for the modification, construction, and installation of catkin packages is known as a catkin workspace.
   - Differential drive: It provides tools that enable the robot to negotiate a turn.
   - LiDAR: This package makes it easier to handle 2D Laser Scanner RPLIDAR.
4) Installation of Gazebo and RViz (Robotics Visualization) softwares.

   Gazebo provides a 3D simulation environment that allows users to test and experiment with various robot designs and behaviors. The robot can be evaluated & tested in difficult or dangerous scenarios without any harm to the robot.

   RViz is a computer tool that shows you a 3D model of a robot and other important information. You can use RViz to see things that the robot's sensors are picking up, like cameras or distance detectors. It also allows users to interact with robot models and other types of data.

5) Converting the 3D model file to URDF (Unified Robot Description Format)

   The Unified Robot Description Format (URDF) is an XML file format used to describe the structure and properties of a robot model. URDF files contain information about the physical properties of a robot, such as its joint configuration, links, sensors, and visual elements.
6) Building a virtual world & importing the robot

   Shown in Fig.8 is a virtual world in the Gazebo software. The robot can be placed inside the room, & the room can be mapped.

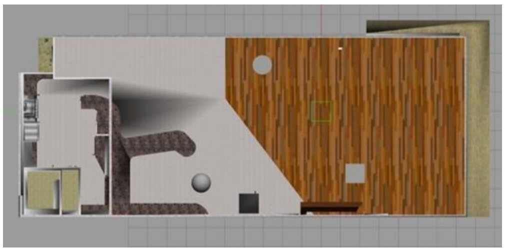

Fig. 8. Top view of a world in Gazebo

7) Installing teleop keyboard for navigating the robot
8) Mapping

1. Place the robot in the environment to be mapped

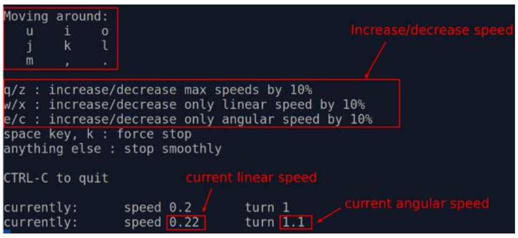

Fig. 9. Teleop keyboard interface

   This is done by loading a robot model (URDF file) into Gazebo and placing it at the desired location.

2. Add sensors to the robot

   Next, sensors need to be added to the robot model to collect data about the environment. We placed the 3D model of the LiDAR sensor on top of the robot.

3. Collect data

   The robot is then moved around the environment with the help of the teleop keyboard while the sensors collect data about the surroundings. The data is typically stored as images.

4. Process the data

   Once the data is collected, it needs to be processed to generate a 2D map. This is done with the help of ROS (Robot Operating System), which provides mapping and localization packages like gmapping, as mentioned previously.

5. Display the map

   Finally, the generated map can be displayed in Gazebo, allowing the user to visualize the robot's environment and plan paths accordingly.

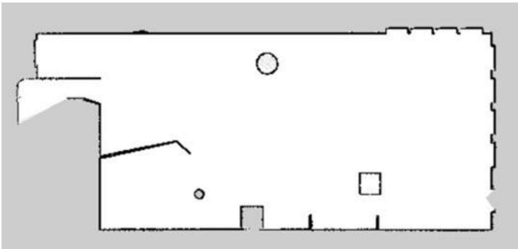

Fig. 10. Generated map

9) Autonomous Navigation

   Once the navigation parameters (robot's maximum speed, acceleration, and deceleration) are set, the navigation stack can plan a safe and efficient path for the robot. Now, Rviz can be launched and configured to show the robot's position, sensors, and other relevant information. At this point, if the robot is given a goal location, it will autonomously navigate to the goal location, while avoiding obstacles and following a safe path.

5. Design

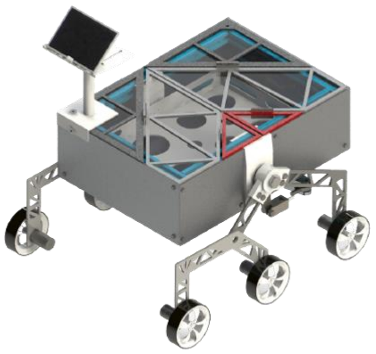

Fig. 11. Iteration 1 design

Fig. 12. Iteration 1 design

6. Conclusion

The demand for autonomous robots in healthcare settings has increased to reduce the risk of infection transmission. The designed robot can navigate an isolation facility and deliver meals in a safe and efficient manner. It can climb stairs and ramps, which are commonly seen hospital infrastructures. There is a need for further testing and evaluation to ensure safety and effectiveness and the potential challenges with implementation in real-world hospital settings, such as navigating complex environments and interacting with humans are to be dealt with. In order to increase its functionality, voice capabilities as well as an ability to sanitize itself can be given to the robot.

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