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Algorithm and Implementation of Human Following Co-bot using 2D LiDAR

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Abstract- **Co-bots-collaborative robots are designed to interact directly with humans in close proximity. Some human-robot collaborative applications like surveillance, clinical services, media outlets, defense, and social associations, may require an autonomous robot to have the ability to distinguish and track a person and to follow him around. The objective of person following with autonomous robots was seen as a special case of object tracking, but it is a challenging task of its own especially when using a short-range sensor like laser range scanner. In this paper, we have proposed and implemented an effective algorithm for detection, tracking, and following a specified target person. An intelligent decision is being made by the control unit of the co-bot based on the information from 2D LiDAR which is mounted at knee height. Finally, the performance of the proposed system is successfully verified through a set of experimental results obtained in a real environment under different scenarios.**

Index Terms-- **2D LIDAR, Co-bot, Human following Co-bot, Human Detection and Following, Laser Range Scanner, Robotics.**

I. INTRODUCTION

Robotics - the combination of sensors, wireless networks, and microcontrollers, in the real world, is on the edge of vast growth which is supported by expanding the availability of sensors, computing devices, actuators, and microcontrollers [1, 2]. Technology has made astronomical leaps and bounds since the days of banging stones together and running from cougars. Robots are pushing the boundaries to meet the requirements of the changing world and the demand for this new technology is driven by human ease and safety. Robots are applied anywhere one of the 3Ds exist: in any job which is too Dirty, Dangerous, and/or Dull for a human to perform [3, 4].

Collaborative Robots or Co-bots are the robots that are interacting directly with humans -either in the same space or in the same intellectual space that is, assisting in augmenting our capabilities as human. Many future application scenarios of robotics envision co-bots to be in close physical interaction with humans [5-7]. For example, on the factory floor, a co-bot shall support their human coworkers with the dull or life-threatening parts of their jobs. In households, co-bot shall enable people to stay independent, even if they have disabilities that require physical help in their daily life – a pressing need for our aging societies. These assistant robots can be used in many domestic and industrial applications. The use of co-bots in surveillance, clinical applications, and social associations has also prospered. Various new applications are likewise developing in media outlets such as accompanying runners or acting as a travel guide. Smart suitcases and trolleys are the practical examples of human following co-bot [8-10].

If co-bot can follow and work together with humans, they will have evolved from workers into our friends. That is, the human-following capability is a significant part of the interaction between robots and people. To perform this task accurately, the robot needs a mechanism that enables it to visualize the surrounding environment and act accordingly. The robot must be intelligent enough to follow a person in a vivid environment and indoor and outdoor places [11-15]. The selection of sensors and techniques employed to get visual information about the surroundings is a very important thing. Therefore, we developed a human detection and following algorithm and implemented it on a two-wheel mobile robot, equipped with a 2D LIDAR for visualizing the surroundings. In the presented algorithm, the field-of-view is distributed into multiple regions allowing the co-bot to ignore another person or objects and to track its target person. Performance of the algorithm is tested and validated in a dynamic environment with different scenarios. Consequently, we attempted to accomplish the following:

1. To resolve the shortcoming of the sensor, lacking the ability to distinguish among humans, by incorporating the idea of multiple regions.
2. To solve the problem of multiple human tracking by introducing the idea of assigning priority level to each region.
3. To solve the problem of limited processing speed, by using only a small section of field-of-view and making the system efficient.
4. To introduce a method for making a well-isolated and power efficient system.

This paper outlines various aspects of human following co-bot using 2D LIDAR supported by a brief literature review in Section II. Remainder of the paper is organized as follows. The design of the mechanical body of the mobile robot and its software aspects are described in Section III and IV. For effective human detection and following algorithm based on laser scanner data, key issues are identified and a suitable algorithm is proposed in Section V. Section VI describes several experiments and results.

II. RELATED WORKS AND PREVIOUS STUDIES

Researchers have addressed the objective of human detection and following in many ways and contributed to the development of a large body of literature. A human-following robot requires several techniques such as human target detection, robot control algorithm, and obstacle avoidance. Various approaches of the following robots have been proposed such as using ultrasonic sensors, Bluetooth & RFID based sensors, vision sensors, voice recognition sensors, laser range sensors, charge-coupled device (CCD) camera, and so on. In recent times, the use of sensors like laser scanners for this undertaking has been well known for quite a few reasons such as a large field of view is produced using laser scanners. Moreover, opposed to vision, they are mainly independent of ambient conditions. Authors in [14] and [12] built up a human identification technique to detect the waist of the target person that utilizes only a single laser range scanner mounted on a two-wheel mobile robot and tested it in a real environment under different scenarios. In both mentioned techniques, concerning the human walking speed and the distance between the human and robot, the speed and acceleration of a robot are adaptive and this is a plus point. Similarly, [3] used a mobile robot system for detecting and tracking the legs of walking humans with a 2D LiDAR in a typical indoor environment. In contrast to our work, their propose system performs the detection using sensors whole field-of-view. Authors in [13, 16-18] also used a mobile robot, however, a hybrid approach for incorporating vision and laser range data is presented to track a human being.

LiDAR data contains little information about individuals, as it typically consists of two-dimensional range information and treats the human as an object. There are mainly two types of methods to deal with data acquired by a 2D LIDAR. The graphical model methodology is based on how a person appears in laser range scanner data. The algorithm proposed by [3] is based on a leg tracker at approximately knee height which detects legs according to a predefined feature list. This technique utilizes graphical feature-based tracking in which if two legs' reflections are sufficiently close to each other, then a human candidate is formed. The other technique is the motion model which depends upon the distance between the target person and the robot. Authors in [12, 19-21] developed an algorithm in which the closest object beyond a fixed distance is treated as an object, which is similar to the solution we proposed, however, the direction of motion of the robot must be set before starting.

III. HARDWARE DETAILS

A. HARDWARE MODULE

We used RPLIDAR A1 as the main sensor for visualizing the surrounding environment. Its processing hardware is developed by Slamtec. Raspberry 3B+ is being used as the brain of the co-bot. Arduino MEGA 2560 and motor driver LM298N are used for controlling DC gear motors. LIPO batteries are used for supplying power. Moreover, XL6009 DC-DC Buck Boost Converter is also used for voltage regulation.

B. DATA FLOW

RPLIDAR A1 is based on laser triangulation ranging principle and uses high-speed vision acquisition, collecting data from surrounding and sending it to Raspberry PI where all the processing of the data, that is, detection of human is being done. Raspberry PI communicates with Arduino MEGA which generates commands for control and direction of rotation of motors based on the position and movement of the person. Data flow is shown in Fig 1.

C. POWER FLOW

We used TCBWORTH 2200mAh battery as a main source for power supply. LM298N motor driver needs 8-12v power and this power keeps fluctuating. Continuous fluctuation in power may cause harm to Raspberry PI which needs 5-6V as operating voltage and it may turn on and off, therefore, we used switches and boost converters incorporating two paths for power distribution. Figure 1 illustrates the flow of power.

This provides necessary isolation between components. Boost converters helps in stabilizing the power as well as regulating it. Moreover, separate switches are added to the design to make the system power efficient. It provided ease during code testing and troubleshooting stage as we would switch off motors and motor driver modules so the motors do not start every time a code is uploaded to it.

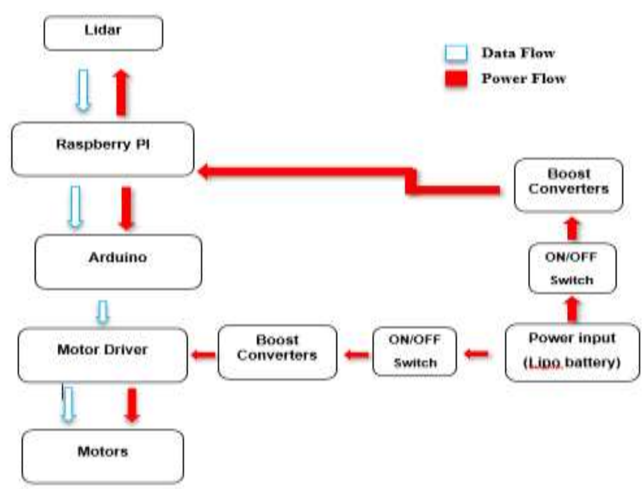

FIGURE 1: Data and Power Flow Diagram

D. MECHANICAL FRAMEWORK

The mechanical body of the co-bot is made into multiple platforms, to provide physical isolation for components. Such

framework allows tidy placement of modules making them easily accessible for connections and troubleshooting.
Moreover, tank-type wheels are chosen to provide a firm grip and stability. It is very important to keep the system stable because data varies if LIDAR is subjected to movement. Therefore, we have kept the platforms lower and employed tank wheels design to achieve the required stability.

IV. SOFTWARE REVIEW

Our human detection and following system is based on ROS which runs on Linux Operating System. Linux has many distributions which are also called Distros. The most suitable distro for our work is Ubuntu as it is user-friendly and there is a wide range of support available for it. Moreover, all the programming is done in python 3.

V. METHODOLOGY AND ALGORITHM

A. MOTION MODEL

The trickiest task of this project was to devise an effective algorithm for human detection and tracking with the limited data of LiDAR.

As mentioned earlier that there are two methodologies to deal with laser scanner data, graphical feature model and motion model. Using the graphical-feature technique, high processing hardware is required because the collection of enough data takes its time and a fast-moving human can leave the field of view before he is even reliably classified as a human. This is particularly the case with the LiDAR as it has a short detection range. Also, human appearance may vary as the relative distance between the target and LiDAR changes.

Therefore, we choose the motion model for human detection and tracking. Motion in range data is typically identified by subtracting two consequent scans which give the distance between the robot and the targeted person as a result.

B. TARGET DETECTION

LiDAR is the main sensor and gives the data in two formats i.e. distance and angle. It sends a laser pulse that strikes the target and returns. Based on the time and the position of the motor (integrated on LiDAR), it predicts the angle and distance of the object placed in its surroundings. By continuous action, it gives us the array consisting of distance, angle range, and opacity (quality of an object to block and reflect light) of the object that is placed anywhere in 360-degree range and within 12m distance.
For effective target detection, we defined a locking area by limiting the range of distance and angles as shown in Fig. 2.

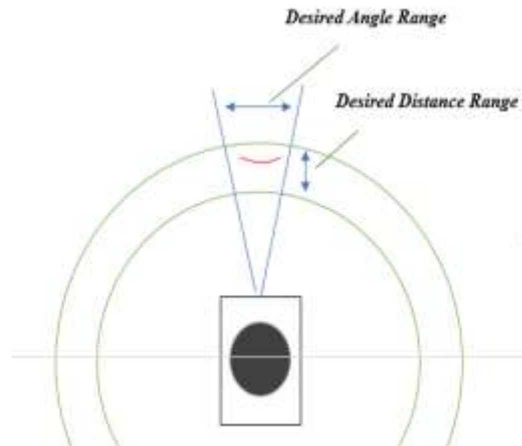

FIGURE 2: Locking Area in LiDAR Scan

If the target is between 0.5 and 1.2 meters in front of the robot, then it will be detected as a human. A person beyond 1.2 meters or closer than 0.5 meters is ignored. A minimum safe distance of 0.5m is fixed so that the co-bot maintains a safe distance from target to avoid a possible collision.

C. TARGET TRACKING

After successful detection of the target person, the next step is to track it. For this, we used 100 angels of LiDAR data and distributed them into three regions. The closest object in the respective region is assumed to be the target. Regions are defined after careful observation and trial-error method, so no more than one human can fit in the locking region. Angles' distribution is given in Tab. I as follows.

Table I: LiDAR Scan Angles Distribution into Regions

Region	No. of Angles	Angle range
Front Region	50 angles	Sub Regions: Front1: 0 to 25-degrees Front2: 334 to 359 degrees
Left Region	25 angles	309 to 333 degrees
Right Region	25 angles	26 to 50 degrees

Moreover, the front region is prioritized over side regions, so if our target is present in the front region and other humans are walking around, the co-bot will only ignore them, successfully following its target.

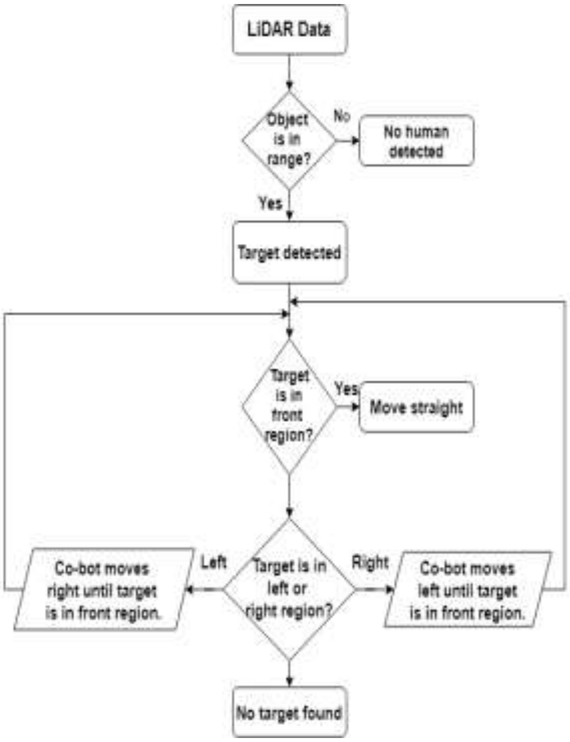

FIGURE 3: Human Detection and Tracking Flow Chart

VI. RESULTS AND DISCUSSION

Progress and performance of algorithm is discussed in this section.

A. TARGET DETECTION AND TRACKING

Initial testing of the target detection algorithm is performed under the assumption that the closest object in range to the front (0º angle) is the target person, that is, if the person is between 0.5m to 1.2m range from the LiDAR, then it is declared as human as shown in Fig. 3. However, with experimentation, we realized that in this condition, if the target person is not at 0-degree angle, then the co-bot loses its target and declares it out-of-range. Console verification of this test is shown in Fig 4.

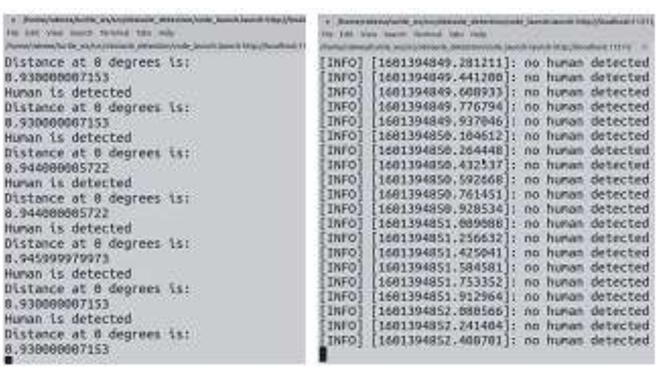

FIGURE 4: Console Verification for Human Detection Test

For effective tracking and following of target, we decided to define regions so the co-bot may not lose its moving target.

B. TRACKING MULTIPLE PERSONS IN SAME REGION

After making three different regions for person tracking, the performance of the algorithm was enhanced. However, with further testing, we noticed that the robot may start tracking two persons at the same time if both are present in the same region.
To avoid this situation, we conducted multiple tests and with the trial and error method, we adjusted the range of distance and angle in such a way that it could contain only a single person.

C. TRACKING MULTIPLE PERSONS IN DIFFERENT REGIONS

After solving the problem of multiple targets in the same region, we encountered the problem of the presence of multiple humans in different regions. In a dynamic environment, if the co-bot is tracking the target person in its front region and another person is approaching the co-bot from a different direction, then the co-bot may start tracking both persons at the same time as shown in Fig. 5.

FIGURE 5: Results for Human Tracking in Front Region

This problem was solved by giving top priority to the front region. Now, if the target person is in front of the co-bot, it ignores the rest of the humans and objects in the surroundings. If the target turns in any direction, then the co-bot turns until the target is back in the front region as shown in Fig. 6.

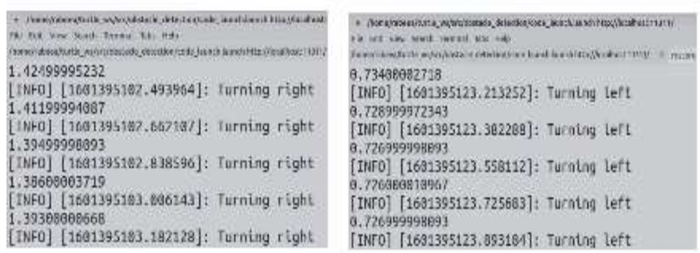

FIGURE 6: Human Tracking in Left & Right Region

This solved the problem of the presence of multiple humans in the surroundings.

VII. LIMITATIONS

There are a few scenarios/conditions under which the system may not produce effective results. Two of them are mentioned below:

A. ALGORITHM LIMITATIONS

During our experiments, we observed that the co-bot may lose its target when it is operated in corridor-like places. If the co-bot gets too close to the wall, then it gets a constant value in one of the side regions due to the presence of the wall but since the target person is in the front region, then the co-bot ignores the wall. However, if the co-bot gets in a situation like it is facing the wall in front, then it starts treating the wall as a stationary target and stops at a distance of 0.5 meters from the wall.

B. HARDWARE LIMITATIONS

Using only 2D LiDAR is not enough for robust tracking of human as it treats human as an object. 3D LiDAR may provide better results as it allows a distinction between humans and objects, however, it is computationally more expensive and requires high data processing speed and Raspberry PI 3B may not be able to process that a large amount of data transmitted by 3D LiDAR.

VII. CONCLUSION AND SUGGESTIONS

In this project, we designed and implemented an autonomous robot that is capable of tracking and following its target human. The algorithm performs well in any dynamic environment, that is, in presence of multiple humans in the surroundings. The tracking accuracy is relatively satisfactory as considering the type of sensor used.

Results can be enhanced by improvising the motion model. An algorithm can be devised by combining both graphical and motion models. Certain conditions can be applied in code which may allow the co-bot to distinguish between humans and stationary objects like walls. Additionally, other sensors can be used in collaboration with LiDAR to produce better results.

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