Person Following Robot with 2D LIDAR: A Categorical Overview

Rabeea khan, Muhammad Zeeshan Yousaf, Asif Ahmed Memon, Sajid Hussain

Abstract— For an autonomous robot, the communication between the person and the robot is the most significant factor. Some human-robot collaborative applications are manufacturing, medicinal services, media outlets, defense and social associations, which require an autonomous robot to have the ability to distinguish and track a person and to follow its human companion. A robot with human following ability is an exemplary however testing issue, especially when executed utilizing low-definition sensors, for example, Laser Imaging Detection and Ranging (LIDAR) sensors. Various applications, particularly, in conditions where a number of people are interfacing, present differing difficulties by adding requirements to the degree of autonomy, the robustness and dynamics of a human following robot. Researchers and analysts have tackled these challenges in different ways and contributed to the development of person following robot. This paper provides a brief overview of the literature by ordering different aspects of autonomous human following behavior of a robot using only LIDAR. Likewise, the analogous operational challenges are acknowledged based on proxemics, type of extracted feature from LIDAR data and its classification. Then, some of the prominent strategies are identified and compared, corresponding applications and limitations are presented under different conditions, and their achievability is analyzed for various scenarios. Moreover, some open issues are featured for future research.

Index Terms— Person following robot; human-robot interaction; human detection and tracking; 2D LIDAR;

1 INTRODUCTION

Person following scenarios emerge when a human and a self-sufficient robot collaborate on a common task that requires the robot to follow the human. Information about nearness, presence, position, and motion state of individual will empower the robot to better comprehend and forestall intentions and actions. Ground service robots following a human while carrying out a cooperative task is the recognized example of person following. Such assistant robots are being used in many domestic and industrial applications. The use of companion robots in surveillance, clinical applications and social associations has also prospered in the course of the most recent decade. Various new applications are likewise developing in media outlets as robots are getting increasingly open for personal use, such as accompanying runners or acting as a travel guide.

In this paper, the issue of people detection from laser scan data acquired with 2D LIDAR is considered. 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 and, opposed to vision, they are mainly independent from ambient conditions. Be that as it may, LIDAR data contain little information about individuals, particularly on the grounds that they typically consist of two-dimensional range information and treats human as an object. Figure 1 shows an example scan from a cluttered office scenario where several people were strolling through the workplace. As it can be observed that people detection in 2D range data is difficult even for humans [1]. Robust techniques to empower person following are subsequently vital in the determination of automated practices and robotic behaviors. Perception, granularity, and interaction the major computational components of a person-following system. The design of each of these components to a great extent relies upon degree of autonomy for the robot and the data classification, which is the type of features extracted from LIDAR data. Moreover, different scenarios (*i.e.*, indoor environment, cluttered environment of office or mall, street) pose distinctive operational challenges and add limitation on the construction, development and dynamics of the robot. Initially seen as a special case of object tracking, person following by autonomous robots before long turned into a challenging task of its own. Variety of different methodologies for a wide range of applications has been acquired in attempts to develop person following robots.

This paper outlines various aspects of the person-following robot using 2D LIDAR and provides a review of the existing literature. In addition, different issues related to the robot and algorithmic designs are identified, operational scenarios are illustrated, and qualitative analyses of the state-of-the-art approaches are presented. Specifically, the contributions of this paper are the following:

Based on proxemics, perception and data classification, a categorization of the person-following techniques is presented along with an elaborate discussion on the underlying algorithms of different state-of-the-art approaches. Operational scenarios for each category are then discussed. Moreover, for different person-following scenarios, key design issues are identified and the core assumptions are discussed. Subsequently, the attributes and overall feasibility of these algorithms are qualitatively analyzed and then compared based on various operational considerations. Furthermore, several open problems for future research are highlighted along with their current status in the literature.

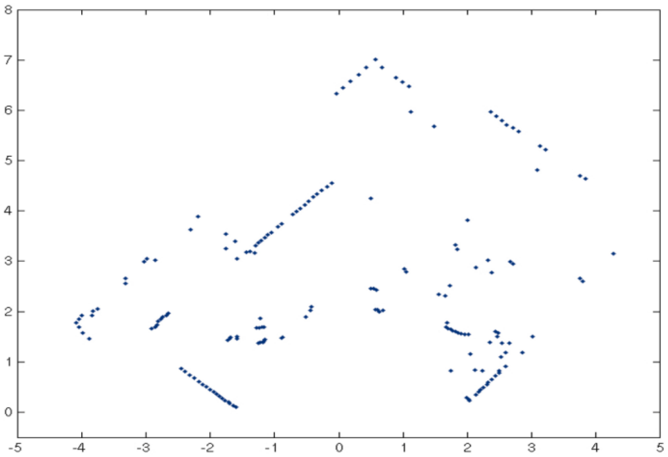

Figure 1: Where are the people? Example scan of an office

2 CATEGORIZATION

Depending on several application-specific factors such as the degree of autonomy (Full or partial) and granularity etc. person following behaviors of a robot using 2D LIDAR can be diverse. The design and overall operation of a person-following robot mostly depend on design choices as well as the mounting height of LIDAR.

In view of above-mentioned attributes, a simplified categorization of autonomous person following behaviors is as follows.

A. Degree of Autonomy

Degree of autonomy or autonomous behaviour of robot alludes to the performance of the robot without external impact. A robot that performs fully autonomously should not only complete the jobs that are desired of them but also somehow set up an association between themselves and the person operating them.

Full autonomy is preferred over partial autonomy in most cases for person-following, for example [1] introduced an approach by which a strong classifier is prepared from simple features obtained by sets of adjacent beams analogous to legs in point cloud data based supervised learning technique using AdaBoost. Similarly, [2] presented an algorithm based on AdaBoost. In this approach, a probabilistic combination of the yields from various classifiers obtained by supervised learning forms a person detector. [3] also introduced an AdaBoost based boosting approach. In this technique, a set of weak classifiers computed from simple geometrical and statistical features are combined in order to learn a strong classifier to form legs of people.

[4] introduced a follow me navigation algorithm in which the nearest object to the robot is chosen so that the robot follows the targeted person or object. Furthermore, a safe distance from it is maintained in order to avoid a potential impact. [5] used a list of predefined features for classification of reflections as clusters. Using the geometric feature of the legs, a human target is generated and tracked only if two clusters satisfy pre-specified conditions to be perceived as legs, and on the off chance that they are sufficiently close. The upside of this technique is that the likelihood of a human objective to really be a human is continually assessed dependent on various features. Consequently, this strategy may be considered as fully autonomous falling into the category of feature-based tracking,

[6] came up with a rather unique idea for position initialization as there are no pre-defined features and position initialization is done with a follow-me gesture. The person moves in front of the robot, stretches out his hand in front of the sensor and draws his hand back t
o his body and just like that position initialization is done. [7] presented an algorithm by which robot controls its own angular and linear velocity thereby maintaining a pre-specified correlative position and orientation with respect to the object being tracked

B. Design Choices

As far as detection and tracking of human is concerned, mobile robot as well as fixed platform systems could be used. Pedestrian detection and tracking systems using LIDARs in jam-packed spots like shopping centers, exhibition halls, streets etc. have become quite popular in recent years among researchers. Fixed platform systems are used by [8], [9] and [10] ,however, on the robotics and mechanical autonomy perspective, the intrigue lies on mobile platforms as, for following a person, robot must be mobile.

[11] proposed a strategy for a one-room tracking area in a domestic environment with cameras placed in the four corners and multiple laser range sensors to detect and track the midsection or waist of a human target. [2] sets up three laser range scanners in the form of a vertical fixed platform such that distinctive body parts including legs, upper body, and head are detected. As the approach does not apply any background subtraction therefore laser scanners can be incorporated to a mobile platform.

[6] and [4] 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, with respect to 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, [5] used a mobile robot system for detecting and tracking legs of walking humans with a 2D LIDAR in typical indoor environment. [12] also used a mobile robot, however, hybrid approach for incorporating vision and laser range data is presented to track a human being. [13] presented a sample-based algorithm to track multiple moving objects using a mobile robot based on JPDAF (joint probabilistic data-association filter). Using a KUKA youBot mobile platform with a 2D LIDAR sensor, [7] proposed an approach which permits to detection and

following of a moving goal e.g. another moving robot in a mutual indoor environment.

C. Granularity

The term granularity is referred to as the number of humans and LIDARs involved in person detection, tracking and following. In case of specific-person following condition, most techniques are good up to two or three persons, where a human is taken as a dynamic object or obstacle, for example, [4] developed an algorithm which treats human as an object and can entertain a single person, however, the technique proposed by [14] provides good results for two persons.

It must be noted that information from a single 2D LIDAR is not always sufficient for identifying and recognizing a person especially for mobile platforms operating on uneven terrains. Therefore, when it comes to detection and tracking, a system of multiple LIDARs in preferred by researches for tracking pedestrians in crowded and cluttered environments or wide and open areas like malls or exhibition halls etc. [2] addresses the problem of detecting people by setting up multiple 2D laser range scanners. Moreover, based on the distinctive appearance or reflection of human feet, a simplified pedestrian's walking model is defined by [15] and Kalman filter-based tracking algorithm is developed. [1] introduced another method for detection using single LIDAR and obtained encouraging detection rates of over 90% in practical experiments in a cluttered office environment.

3 STATE-OF-THE-ART APPROACHES

Perception, data classification and proxemics are the major computational segments of an autonomous person following robotic system. This section discusses these components of the state-of-the-art methodologies and their underlying algorithms.

A. Perception

Perception refers to classification of the environment's data gathered by LIDAR. From a set of raw data provided by one or several LIDARs, perceiving the position of the person with respect to itself is a fundamental task of a person following robot. In order to do this, it is necessary to develop data classification technique so as to process the laser scan data. The state-of-the-art perception techniques and ways for object following or object tracking, in general, can be of two perspectives: feature perspective and model perspective (see Figure 2).

Our discussion is schematized based on the feature perspective since it is more relevant to the person following algorithms. Additionally, different aspects of using graphical feature perspective and motion models are also included in our discussion.

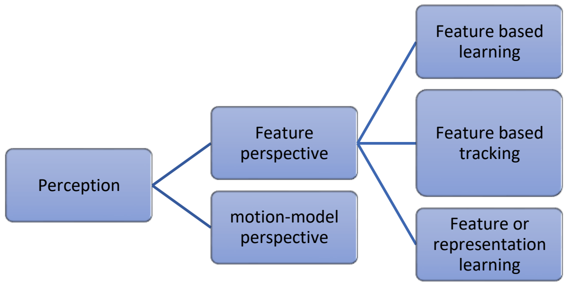

Fig 2: Perception techniques

a) Feature perspective

Feature perspective deals with the number of specific type of objects detected in laser scan data. Based on the algorithmic usage of the input geometric features, perception techniques can be further categorized into feature-based tracking, feature-based learning, and feature or representation learning.

i. Feature based learning

[1] developed an approach by which a strong classifier is prepared from simple features obtained by sets of adjacent beams analogous to legs in point cloud data based supervised learning technique using AdaBoost. [6] also developed a method based on supervised learning technique. In this technique, geometric features extraction is done in order to detect waist of the target person. Additionally, they also proposed a human following algorithm that uses an adaptive acceleration function to allow the robot to catch a human target in a more effective manner, and applies an obstacle avoiding function to eliminate the risk of any kind of collision. Likewise, [2] developed an approach based on supervised learning technique in which three laser range scanners are set up in the form of vertical platform such that distinctive body parts including legs, upper body, and head are detected. A robust final classifier is then obtained from the outputs combined in a probabilistic manner.

ii. Feature based tracking

The algorithm proposed by [5] is based on a leg tracker at approximately knee height which detects legs according to predefined feature list. This technique utilizes feature-based tracking in which if two legs' reflections are sufficiently close to each other, then a human candidate is formed, after which the human is tracked using the leg images. In many LIDAR based approaches, scanners are installed at the height of the human torso and people are extracted as single clusters which are then tracked with a filter [16], [17]. [18] also extracted single blobs from the LIDAR data but they tracked clusters of moving objects whenever they are in close proximity of each other based on the assumption that people tend to move around in groups. Laser data of the torso region, however, does not provide much information for the classification of the detected objects. The other approach is to look for the leg hypotheses [7], [3], [19], [20], sometimes dictated by the small size of the robot when nothing other than the legs are visible.

iii. Feature learning

[21] introduced a method based on geometric feature learning and matching. The range data is distributed into clusters with a jump distance condition and a set of geometric rules is applied to each cluster so each of them would be classified either as a line, a circle or pair of legs. Additionally, various techniques for extracting line models from point cloud data have been introduced, among which the most popular are clustering algorithms based on Hough transform [20] , [22] and split-and-merge algorithm in which the scan is recursively subdivide into sets of adjacent points that can be approximated by line [23], [24], [25]. Likewise, [26] performed circle detection using least squares algebraic circle where a leg is pre-defined as a circle with an additional diameter condition.

b) Motion-model perspective

Motion in range data is typically identified by subtracting two consequent scans which gives distance between the robot and the targeted person as a result. If the robot is moving itself that is following the target, then in that case the scans have first to be aligned and adjusted, e.g., using scan matching. Furthermore, based on whether or not any information or condition about the appearance or motion of the target is pre-defined, they can be categorized into model-based and model-free techniques.

In this context, the extraction of reflections of legs by the detecting moving blobs that are close enough as well as appear as local minima in the laser scan is a quite popular approach among researchers [8], [13], [12], [27]. Another method introduced by [14] deals with feature-based learning technique as well as motion model in order to detect and track a person. Using a fusion of convolutional neural networking and Kalman filter, pair of legs of moving person is detected. This method provides good results in complex situations, however, walking speed is assumed to be constant. [4] developed an algorithm in which closest object beyond a fixed distance is treated as an object, however, the direction of motion of the robot must be set before starting. Furthermore, based on the distinctive appearance or reflection of human feet, a simplified pedestrian's walking model is defined by [15] and Kalman filter based tracking algorithm is developed.

A downside with the motion features is that if the targeted person stop moving then robot can possibly lose the target hence, only moving people could be found, however, [28] extended the method of [27] by the ability to detect and track also people standing still. There algorithm showed good results in a typical domestic scenario as well as in jam-packed environment.

[29] have worked on the problem of recognition of reflected beams by dynamic objects. In this technique, individual beams are considered separately and EM is applied in order to determine, if a beam has been reflected by a dynamic object such as a person or not.

B. Proxemics

Proxemics refers to appearance of person in laser scan data and the pose of the person with respect to the position of the robot or LIDAR. In proxemics, the usual method to detect and track people is to keep them in front of the robot, since it is the usual place where LIDARs are installed. Then, it is required to settle on which part of the body of the person is used for follow-up. Clearly, the appearance of people in LIDAR data largely relies upon the mounting height of the LIDAR: at the height of midsection of human body, a human midsection, that is, torso is seen as a single blob in range scan, while individual and separate smaller blobs appear at feet height. Usually, the mounting height of the sensor is often chosen not only to suit the requirement of task and to facilitate the research but also by the relevance, safety regulations and the form factor of the robot. Safety regulations, for instance, require LIDARs to be installed as low as possible like at foot height as it is more stable and steady position. However, at this height, single blobs are poor models for the indication of people which leads to leg-tracking hypothesis being a suitable approach for people tracking using 2D LIDAR. However, mounting height of LIDAR is also chosen between torso, waist in quite a few cases and scenarios.

a) Legs hypothesis

In this section, we are contemplating the issue of identifying individual or pairs of legs and ability to track them by the detecting moving blobs that appear in the laser scan data [30], [31], [32], [33]. This approach is quite famous despite the fact that it has a drawback that when the robot identifies human legs, it might be confounded in choosing which two legs establish a pair, or may mistake it for legs of chair or table and may also sometimes fail to recognize a female wearing a long dress (see fig 3). [13], [12], [27], [34] also used this methodology however, under the condition that nothing other than the legs of targeted person are visible.

[13] utilized Bayesian filtering in order to estimate the number of people in the scan to detect and track various objects in the 2D range scan of the robot based on the number of moving blob in the laser range scan. However, as this approach is based on motion model therefore, only moving humans would be detected, and therefore this method gives poor results in cases when people are stopping by frequently and in crowded environments like shopping malls, exhibition halls etc (where the number of moving blobs is misleading).

The use of the geometric features of human legs based on walking motion model has been tested by [34], but it lacks adaptive speed function. [21] introduced a method based on geometric feature learning and matching. The range data is distributed into clusters with a jump distance condition and a set of geometric rules is applied to each cluster so each of them would be classified either as a line, a circle or pair of legs.

Other research, [3] proposed an algorithm to detect individual legs and used AdaBoost for supervised learning. In a second level, they developed a multi-target advanced detecting and tracking method by which peoples' state of motion is deduced using leg observations.

Likewise, another research [35] introduced a tracking method which used a combination of Kalman filters a Global Nearest Neighbor filter to infer behaviors over respective scans and resolve the scan-to-scan data association hitch. This algorithm considered a pair of legs, rather than individual ones but it has a downside of using two different steps approach which could be done in a single step by a more general scheme based on machine learning. Also, the authors concede the setback of adapting their impromptu proposal.

Other researchers [36] have utilized Support Vector Machines to gain proficiency with the various patters and structures that can develop in robot surroundings analogous to the legs of moving or still people. However, this technique is limited in a sense that it can efficiently keep track of only a single person in controlled and limited circumstances.

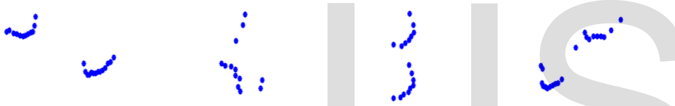

Fig. 3. Typical range readings from legs of people. As can be seen, the appearance can change drastically, also because the legs cannot always be separated. Accordingly, the proper classification of such pattern is difficult.

b) Waist hypothesis

[4] introduced a human identification technique to detect the waist of the target person that utilizes only a single laser range scanner. However, in this technique, the speed and acceleration of a robot are adaptive and this is a plus point. [6] introduced a similar algorithm, however, no predefined features are required for initialization. [8] applied the same approach by positioning laser scanners targeting the waist height of walking people.

Even though person detection and following with LIDAR positioned at waist height have been used by researchers, the likelihood of facing occlusions at the height of waist is much higher than at legs and feet level, and range reflections from not only swinging arms, but also other unpredictable factors, e.g., hand bag, coats, etc., are difficult to be modeled for an accurate tracking.

c) Feet hypothesis

[37] pursue a multi-sensor approach to people tracking using multiple laser scanners at foot height and a monocular camera in which moving blobs of 15 cm diameter are extracted as feet of candidates. Two feet candidates at a distance of less than 50 cm are treated as a step candidate. Another tracking algorithm utilizing Kalman filter is introduced by [15], where a pedestrian's walking model based on the general manifestation of moving feet is defined assuming that moving objects are the feet of normal pedestrians only.

d) Torso and multiple body parts hypothesis

Despite the fact that, 2D LIDAR data of the torso region does not provide much information for the classification of the detected objects, in many approaches, a single state is used to represent a person that expresses torso position and velocities.

[2] sets up three laser range scanners in the form of a vertical platform such that distinctive body parts including legs, upper body, and head are detected. (see fig 4).

[38] proposed an algorithm with face and head-shoulder detection methods. [39] presented a solution based on the trajectory of the torso. Another algorithm using the back of the torso and the shoulder is also proposed by [40].

In other related research on people detection and tracking using laser scanners, sensors are mounted at the height of the human torso [29], [31], [32].

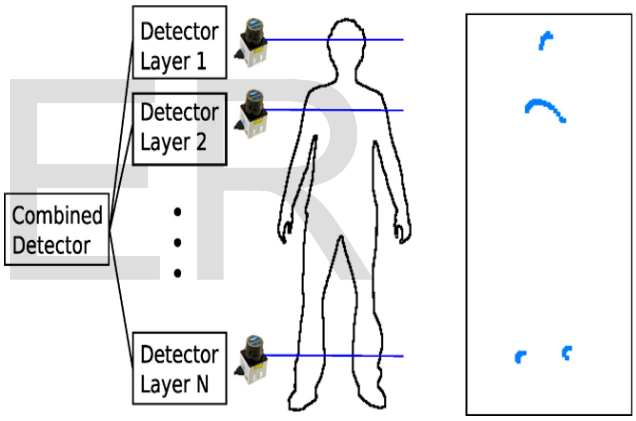

Fig. 4 The left image depicts the arrangement for the complete system with 2D range scans positioned at different layers. The right image shows examples of segments representing body parts at three different heights: legs, upper body, and head.

4 CONCLUSION

Person detection, tracking and following using 2D LIDAR by autonomous robots have various significant applications in industry. Their utilization in social settings and for entertainment purposes have flourished in the course of the most recent decade too. Different aspects of the person following problem from various perspectives have been approached by many researchers which contributed to the development of a vast literature. This paper makes an effort to present an overview of this large body of literature in a categorical fashion. First, the design issues and behavior of robot including degree of autonomy, interaction and granularity for person following robots using 2D LIDAR are presented. Then, the state-of-the-art methods for perception and proxemics are discussed. In addition, several operational considerations for applying these methods, underlying assumptions, and their feasibility in different cases are compared and analyzed.

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