Development of Autonomous Wheelchair for Indoor and Outdoor Traveling

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Abstract. In order to assist elderly people and disabled people, this paper describes development of autonomous wheelchair to travel in indoor and outdoor environments for providing traveling ability to any where. For this aim, the autonomous wheelchairs should have traveling-capability without choosing indoor and outdoor environments. Position detection is a key technology for autonomous driving since people decides a traveling direction from a current position and a destination. GPS is a fundamental technology for position detection. However GPS is not available in indoor cases, and GPS is not always available in outdoor cases when tall buildings occlude satellites. In these cases autonomous wheelchair has to detect a self-position by other sensor systems. In this study we have adopted a localization system utilizing 3D maps and a 3D laser range finder. By the 3D localization system our wheelchair system can detect a self-position robustly if the wheelchair is surrounded by obstacles such as pedestrians. To avoid collision our wheelchair system uses short and long term planning. The short planning finds a safe motion-pattern from every conceivable pattern by the simulation on a map. The long term planning generates a feasible route to destination. If the route generated by the long-term planner collides to some obstacles our wheelchair avoids collision by the short term planning. By the localization system and the planning system our wheelchair could operate in public spaces.

Keywords: Autonomous vehicle · Wheelchair · SLAM

1 Introduction

We have developed an autonomous wheelchair system for assisting travel of elderly people and disabled people in order to help their daily living. This paper describes about our developed autonomous wheelchair systems.

Autonomous driving systems have spread out toward many applications that are airplanes, ships, trains, cars and small personal mobilities such as wheelchairs. Especially, autonomous driving cars and wheelchairs have difficulty compared with other vehicles because environments using these vehicles are complicated.

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There are many obstacles such as cars, pedestrians, etc. in roadways and sidewalks. Autonomous driving cars and wheelchairs have to detect the obstacles to prevent collisions. Moreover, GPS can not always detect accurate position in the roadways and sidewalks because upper tall buildings reduce the precision of GPS for occluding satellites. Autonomous driving systems control the self-velocity by comparing target routes and current position. Inaccurate positioning triggers undesirable driving to autonomous vehicles. The vehicles should have other devices to detect accurate position when GPS is unavailable.

In comparison with autonomous driving cars, the wheelchairs have to travel on not only outdoor environments but also indoor environments. There are no clear rules for smooth traffic in the environments using the wheelchairs. The wheelchairs can freely travel on any routes. Similarly, the pedestrians freely walk in the environments. The autonomous driving wheelchairs have to decide a route for smooth traffic in response to motion of pedestrians. In roadways cars and pedestrians move under the traffic regulation. The traffic regulation restricts routes for cars and pedestrians. The cars can only move forward, and can not move backward on lanes. Basically, autonomous driving cars avoid collisions by speed control. Against the cars, the wheelchairs have to decide a route to avoid collisions.

Autonomous driving wheelchairs have other difficulty for positioning in comparison with autonomous driving cars. In roadways there are specific features for the traffic regulation, which are traffic signs, white lines, pedestrian crossings, etc. Autonomous driving cars can use the features as landmarks for positioning. Against the case of cars the specific features do not always exist in the environments using the wheelchairs. Autonomous driving wheelchairs have to detect self-position without using the specific landmarks when GPS is unavailable.

In this paper, we introduce our developed autonomous driving wheelchair [2] that can detect self-position without using specific landmarks and can decide a route in response to motion of pedestrians. Our autonomous wheelchair can travel in indoor-outdoor environments by the self-positioning and the route planning seamlessly.

2 System Architecture

Figure 1 is our developed autonomous wheelchair "MARCUS". Our wheelchair equips a 3D laser range finder (3D-LRF) unit for making maps, two wheel encoders for measuring self-velocity, and a 2D laser range finder (2D-LRF) for collision avoidance.

The 3D-LRF unit obtains 3D points by rotating a 2D-LRF, which is a LMS-151 manufactured by SICK. The rotation axes are a roll axis and a pitch axis. The range of rotation angle is from −22.5 degree to +22.5 degree for each axis. The measurement time of obtaining 3D points until rotating the range is 1.5 s Our wheelchair uses the 3D-LRF unit for making 3D maps, and does not use the unit for collision avoidance because the length of time for 3D scanning is long.

The 2D-LRF is a UTM-30LX manufactured by Hokuyo Automatic Co. LTD. The 2D-LRF is rigidly clamped to the wheelchair frame, and does not rotate.

Fig. 1. Our developed autonomous wheelchair.

In comparison with the 3D-LRF unit this 2D-LRF can detect the obstacles rapidly. The scanning time is 25 ms. Our wheelchair uses this sensor to avoid collision for this rapid scanning.

The two wheel encoders measure self-velocity from wheel angular velocity of left and right wheels. Our wheelchair detects self-position by computing relative displacement from wheel encoders, and by correcting the displacement by matching 3D-scanning data and map data. The details of localization and mapping is written in the next section.

3 Localization and Mapping

For detecting self position in outdoor and indoor environments our wheelchair performs 3D scan-matching by using the 3D-LRF unit. This section describes the positioning method.

3.1 Localization

To detect a correct position after movement, we adopted a monte carlo localization (MCL) based algorithm [4]. MCL finds a correct position from position-samples that are generated randomly by using a dynamics model of wheelchair. If many samples are generated, the possibility to find a correct position becomes high. Evaluation of correctness of a position-sample is done by shape matching. If a position-sample is correct, a scanned shape by LRF matches to map-shape when the scanned shape is drawn from the sampled position. The evaluation is to calculate similarity between matched shapes.

Our wheelchair calculates the similarity by 3D shapes to gain robustness of localization. In the environments running wheelchairs there are not only static objects but many dynamic obstacles such as pedestrians, cars, etc. If using 2D-LRF only, scanning shapes of environments becomes difficult when the wheelchair is surrounded by these obstacles. To prevent this surrounded case our solution is to scan many direction. The possibility to scan mapped objects becomes high by scanning many direction. For this reason our wheelchair uses 3D scanning.

3.2 Mapping

The localization system of our wheelchair requires 3D maps. To obtain 3D maps we adopted Rao-Blackwellized particle filter (RBPF) that is extension of MCL. The basic concept of RBPF is to generate many samples of map, and to find a correct map from the samples. When data size of a map is large, RBPF becomes difficult to construct a map in realtime because many samples require huge memory and computational cost. To solve this problem we have proposed a improved RBPF method [1] that is sub-map dividing and re-alignment. In our method the number of map-samples is one. To find a correct map our method divides the map and realigns sub-maps by generating samples of alinement between sub-maps. By this re-aligning procedure our method can generate a correct 3D map although the memory size of 3D map is large because our method does not require generation of map-samples.

4 Collision Avoidance and Route Planning

Our wheelchair is driven by short term planning and long term planning to avoid unsafe self-driving [3]. The short term planning considers the wheelchair motion in a few seconds. This planning is corresponding to collision avoidance, and is a crucial issue against safety. The long term planning considers the route until arriving at a destination. This planning aims to generate a feasible route to arriving at a destination.

4.1 Collision Avoidance

For collision avoidance our wheelchair uses the dynamic window approach (DWA)[5]. DWA searches target wheel-velocity without collision from every conceivable pattern of wheel-velocity. In DWA vehicle-controllers utilize patterns of wheel-velocity that are possible by acceleration and deceleration in performance limitations of vehicles. DWA searches a pattern of wheel-velocity without collision by simulation. In the simulation DWA checks the collision on environment-maps generated by LRF. When a virtual vehicle continues a velocity-pattern within a specified time, and does not collide on the map, DWA adopts the non-colliding pattern.

4.2 Route Planning

For route planning in outdoor and indoor environments our wheelchair adopts A* algorithms on the 3D-map generated by our mapping method. A* algorithm finds a shortest path on the map by combination of motion patterns. Each motion patterns are simple. For example, the patterns are forward movement, backward movement, left and right turns. By the combination of motion patterns A* algorithm generates a shortest path and can generate a feasible route in response to dynamic obstacles.

Our wheelchair system has two motion planner that are the short and long term planner. If there is no collisions in the simulation, the system uses a result of long term planner. Conversely, If there is a collision in the simulation, the system uses a result of short term planner. Basically, our system takes precedence of the short term planner.

5 Experiments and Discussions

We have performed an experiment of 3D map building by using our RBPF algorithm described in the Sect. 3.2. Figure 2 shows the mapping result. The map size is 350m $\times$ 250m, and was constructed in realtime. From this experimental result our wheelchair can perform autonomous driving after construction of a map immediately.

This rapid map construction provides portability to our autonomous wheelchair because if a map is not constructed our wheelchair generates a map in realtime and can perform autonomous driving immediately. Our wheelchair can operate in any places because our system can generate maps immediately.

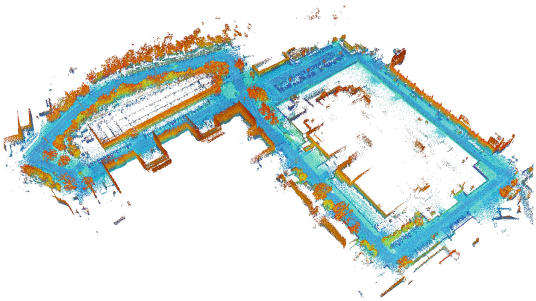

Fig. 2. A 3D map generated by our RBPF algorithm.

Figure 3 shows an experiment of autonomous driving in public space. Our wheelchair could operate without any incident in the public space by the short and long term planning. The short term planning provides high reliable collision avoidance because this planning finds out a safe motion-pattern from every conceivable pattern exhaustively. By combination of the short an long term planning

Fig. 3. Experiment in a public space.

if the route planning generate a path collided obstacles our wheelchair can avoid collision because our system takes precedence of the short term planner.

6 Conclusion

In this paper we have described a development of autonomous driving wheelchair. In order to travel indoor and outdoor environments we have developed a localization method and a mapping method on 3D maps. By using 3D map based localization our system can operate in indoor environments and in outdoor environments in which GPS does not function for occlusion of satellites. To realize reliable collision avoidance our wheelchair has short and long term planning. The short term planning finds a safe motion-pattern from every conceivable pattern by the simulation on a 3D map. The long term planning finds a feasible route to a destination. If the long term planning generate a route with collision our system avoids the collision by the short term planning. By the combination of planning methods our system gained reliability for collision avoidance. In the experiment our system operated without incidents in public spaces. As a future work we will study this system in various environments to get informations for improving the system from passengers and pedestrians about comfortability and safety.

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