Autonomous Locomotion Based on Interpersonal Contexts of Pedestrian Areas for Intelligent Powered Wheelchair

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Abstract. In a rapidly aged society, providing mobility aids such as motorized wheelchairs is becoming increasingly important. Although such mobility aids have recently been developed with autonomous locomotion functions, their technologies and locomotive styles are basically based on unmanned vehicles, not on welfare mobility aids. In order to realize harmonious autonomous locomotion, this research proposed the concept of "Interpersonal Contexts on pedestrian areas", and developed prototype technologies utilizing the contexts: velocity control based on interaction prediction of surrounding pedestrians, and interactive collision avoidance based on surrounding mobility type. This paper explains briefly their functions and results, and discussed their utilities based on the interpersonal contexts.

Keywords: Autonomous Vehicle, Human-Machine Collaboration, Collision Avoidance, Interactive Safety.

1 Introduction

1.1 Motivation

Since Japan has become a Super Aged Society, enabling the elderly's continued mobility to allow for outings is a major issue that is closely related to the maintenance of health. Electric powered mobility devices can help the elderly who have difficulty walking and participating in social activities. For the elderly who have decreased locomotive abilities, various types of mobility scooters have been developed. However, decreased cognitive abilities and judgment as a result of aging sometimes make it impossible for users of mobility aids to drive, even if they could drive previously. For such aged users, intelligent mobility aids which have functions of autonomous locomotion can be helpful.

1.2 Existing Technologies of Autonomous Locomotion

For autonomous vehicles moving in the crowded pedestrian areas, not colliding with other traffic participants is important. Researches in the field of mobile robots have

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contributed developments of algorithms of collision avoidance. For example, Khatib[1] proposed Potential Field Method, which steered mobile robots based on the artificial potential. Similarly, Fox et al.[2] developed Dynamic Window Method. These methods were designed for the mobile robots in relatively static situations. After these pioneer researches, various methods for collision avoidance have been developed. Since the desired fields where robots were desired to be utilized had spread into our living environment, much more dynamic methods of collision avoidance became necessary. Human-symbiotic robot "EMIEW" developed by Hosoda et al.[3] achieved collision-free locomotion based on sensing and prediction of velocities of surrounding traffic participants. As these researches achieved, technologies of collision-free autonomous locomotion were realized at a certain level. However, many existing studies focused mainly on numerical algorithms of collision avoidance, and not on styles of autonomous locomotion. They developed avoiding algorithms basically based on only physical indices such as proximity, direction and relative velocity between obstacles and mobile robots. Some researches considered autonomous locomotion as continued avoidances for the pedestrians, who were substitutions of obstacles. Other researches realized the autonomous locomotion by always stopping the vehicle in front of pedestrians. This research thought that such uniform styles of collision avoidance were not always effective for harmonious autonomous locomotion, which was safe, smooth and acceptable locomotion in other words. Therefore, this research proposed and developed functions of harmonious autonomous locomotion based on "Interpersonal Contexts", which enabled intelligent mobility aids to interact with other traffic participants.

2 Concepts of Harmonious Autonomous Locomotion Based on Interpersonal Contexts

2.1 Necessary Requirements for Harmonious Locomotion on Pedestrian Areas

Generally speaking, safe locomotion is different from smooth and acceptable locomotion; further, smooth locomotion is different from acceptable locomotion. Fig. 1 shows our concept of hierarchical characteristics of harmonious locomotion, which is applied to not only autonomous locomotion but also human-operated locomotion. For realizing safe locomotion, vehicles have only to avoid collisions. Unmanned carts in automated factories, which do not need smooth and acceptable locomotion, are typical examples of this category. For realizing smooth locomotion, vehicles have to move with soft velocity, acceleration and yaw rate. On the contrary, for realizing acceptable locomotion, vehicles have to move by considering either rules or contexts. Automobiles and welfare mobility aids are examples of these categories. Publicness of locomotion environment divides these categories: welfare mobility aids on private areas need only smooth locomotion, and those on public aresa need acceptable locomotion. On these points, harmonious autonomous locomotion of welfare mobility aids is not realized only by the exiting robotic technologies, which have already realized smooth autonomous locomotion.

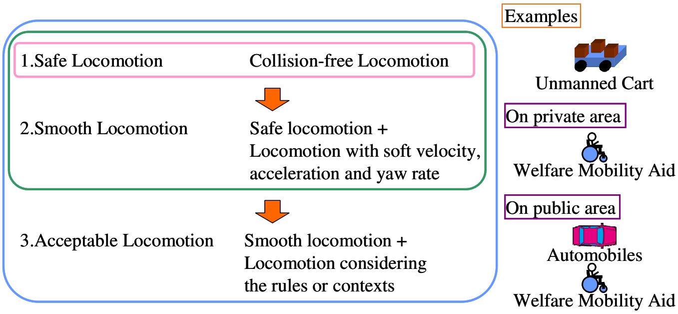

Fig. 1. Hierarchical Characteristics of Harmonious Locomotion

Fig. 2 shows the appearance of a typical sidewalk, which is our target locomotion environment. Pedestrians, wheelchair users, mobility scoter users, and bicycle riders travel on common sidewalks, although bicycle riders have limited permission for most areas. Because their locomotion velocities vary widely as shown in Fig. 3, interactions such as overtaking by changing lanes, making a sufficient margin for safely overtaken, and avoiding oncoming traffic participants, happen very often. In addition, there are no defined rules for such interactions in this environment. Thus, contexts are the dominant factor of the acceptability of locomotion on pedestrian area. The lack of the rule and existence of ambient contexts are discriminative differences from the cases of other vehicles. On this point, Fig. 4 shows characteristics of locomotion that was considered in this research. For example, locomotion of trains on railways is the typical example of the most rule-based locomotion. On the other hand, locomotion of welfare mobility aids on pedestrian areas is that of the most context-based locomotion. Locomotion of automobiles in public roadway is partly rule-based and partly context-based.

Because the rule of locomotion is not obvious, traffic participants on pedestrian areas need to share contexts for the harmonious locomotion. Likewise, even intelligent mobility aids need to share contexts. In other words, intelligent mobility aids should become not a special machine but a usual traffic participant on pedestrian areas. In this situation, usual traffic participants pay attention to other traffic participants for harmonious locomotion. They confirm not only positions and velocities of surrounding traffic participants but also characteristics of them. In addition, they evaluate

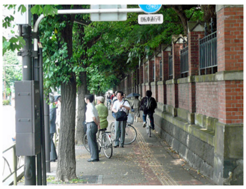

Fig. 2. Appearance of Target Locomotion Environment (Left side)

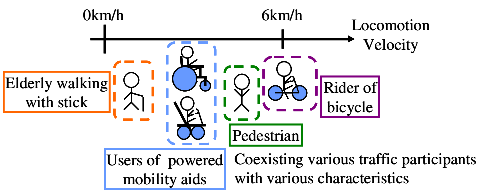

Fig. 3. Locomotion Velocities according to Mobility Type of Traffic Participants (Right side)

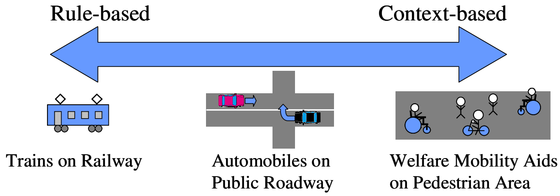

Fig. 4. Characteristics of Locomotion from the Aspect of Dominant Factor of Acceptability

near-future traffic situations as well as current ones. Moreover, evaluation criteria for such information change according to contexts. This research thought that the management of such information about surrounding traffics seemed the key of harmonious locomotion; besides, this research defined those kinds of information as "Contexts on pedestrian areas". Furthermore, this research thought that harmonious autonomous locomotion of intelligent mobility aids would be realized by developing the recognition system of contexts on pedestrian area.

2.2 Various Contexts on Pedestrian Areas

There are various kinds of contexts on pedestrian areas. For example, pedestrians change locomotion path suddenly if there are some attractive stores on their way. In another situation, traffic participants change their locomotive velocities if the climate changes suddenly. In the situations of some disasters, traffic participants change their locomotion styles from a normal locomotion to an emergency escape. This research thought that these examples were all contextual locomotion: the first one was an example of place-based context, the second one was that of climate-based context, and the third one was that of emergency-based context. Thinking of and sharing these contexts is necessary to realize the harmonious locomotion.

Some of existing researches developed the technologies for autonomous locomotion partly based on contexts, although they did not mention the concept of contexts. For example, Ohki et al. [4] developed a collision avoidance method for rescue robots. Their method utilized an emergency-based context and realized prediction of pedestrians' locomotion in a panicked state. As this research realized, autonomous locomotion considering the contexts would be useful.

2.3 Interpersonal Contexts for Autonomous Locomotion on Pedestrian Areas

Most of existing researches of intelligent mobility aids proposed algorithms of autonomous locomotion based on technologies of unmanned vehicle; they considered surrounding objects as obstacles. However, this assumption is not true because surrounding objects on pedestrian areas are not obstacles but other traffic participants. Moreover, intelligent mobility aids are not an unmanned vehicle but welfare vehicles which someone rides on. On this point, assumption and information used for existing intelligent mobility aids have not been fitted to situations of the real world. Thus, interpersonal contexts are much more necessary for harmonious autonomous locomotion of welfare mobility aids. For the welfare mobility aids which someone ride on, not only physical aspects of locomotion such as acceptable acceleration and velocity but also emotional and psychological aspects should be considered in order to improve acceptability of locomotion.

For example, although excessively safe styles such as always stopping the vehicle in front of other traffic participants without considering contexts could realize collision-free locomotion, it would give the diffident feeling to the riders. Since the purpose of this research is to realize continuous outings of the elderly by the intelligent mobility aids, such negative locomotion can not achieve our purpose. Unforced outings of the elderly are different from simple transportations of them, and locomotion styles should not be disincentive for outings. Motivating effects of locomotion styles are essential for our purpose.

On the contrary, although quickly avoiding all oncoming traffic participants would realize speedy locomotion, it would impress rough images on surrounding traffic participants. This kind of locomotion would not achieve the harmonious locomotion because pedestrian areas are not private locomotion environment. Therefore, even emotional and psychological aspects are as important as physical aspects for harmonious locomotion. For considering such aspects of locomotion, various locomotion styles of usual traffic participants seem the key.

For the locomotion on the pedestrian areas, keeping the adequate proximity to surrounding traffic participants is important. Enough proximity allows traffic participants to move smoothly even in the suddenly changeable situations; further, it gives them comfort. On this point, Liu et al. [5] investigated the margin proximity of pedestrians' avoidance, and organized as concept of "personal space". The important point is that personal space is not determined by physical indices such as limit acceleration but by natural behaviors of traffic participants including physical, psychological and emotional factors. In addition, usual traffic participants predict the situations of near future, and adjust the locomotion. If they do not predict the situation at all, the traffic flows of pedestrian areas are sometimes jammed. In such situations, making traffic flows smooth by active acceleration is sometimes better than jamming them by excessively slow and safe locomotion. Since adequate locomotion depends on the contexts, predictions of changes of traffic flow and active controls of velocity are important in some contexts.

As another aspect of pedestrian areas, various kinds of traffic participants coexist. Since their locomotion abilities and social characteristics vary widely according to their mobility type, considering the characteristics of surrounding traffic participants is necessary to realize the harmonious locomotion. For example, it would be strange that the elderly who has decreased locomotive abilities give way to the healthy young who has good locomotion abilities in the situation where either of them needs to avoid. This situation has both a social problem and a problem in locomotive abilities. Implementation of that kind of technologies of unmanned vehicles into welfare intelligent mobility aids has the possibility of making such socially and emotionally strange vehicles. On this point, Kin et al. [6] revealed an implicit order between the types of traffic participants by the survey of attitudinal priorities. Usual traffic participants become acceptable to conform such implicit orders.

These are the examples of interpersonal contexts on pedestrian areas although there are still various interpersonal contexts. This research thought that implementation of the concept of interpersonal contexts into technologies of welfare mobility aids made it possible to realize harmonious autonomous locomotion. The important point is that autonomous locomotion based on interpersonal contexts would contribute to improvements of not only acceptability but also safety and smoothness of locomotion. If the autonomous vehicle conform the interpersonal contexts, they would be accepted as the harmonious traffic participants in spite of machines. This research thought that only such harmonious intelligent mobility aids can realize continuous outing of the elderly.

3 Application Examples of Utilizing Interpersonal Contexts

As the prototype technologies of harmonious autonomous locomotion, this research proposed two kinds of elemental technologies: velocity control based on interaction predication of surrounding pedestrians, and interactive collision avoidance based on surrounding mobility type. This paper explains the concepts and brief results of each technology.

3.1 Hardware of Prototype Intelligent Powered Wheelchairs

Fig. 5 shows the appearance of the prototype of intelligent powered wheelchair used in this research. This vehicle has a laptop for calculation, a monocular camera for capturing video images, and two LIDARs for measuring the distance information. In addition, based on the time-series measurement of the positions of traffic participants, the vehicle estimates their velocity vectors.

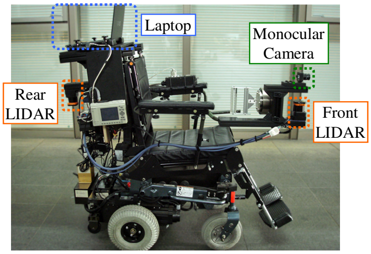

Fig. 5. Developed Prototype Intelligent Powered Wheelchair

3.2 Velocity Control Based on Interaction Prediction of Surrounding Pedestrian

Since locomotion velocities of traffic participants are various, frequent locomotion interactions such as over taking and facial avoidance are conducted on the narrow sidewalks. In such situations, prediction of local traffic is effective for harmonious autonomous locomotion. For example, if the locomotion path of surrounding traffic participants apparently cross the locomotion path of the vehicle in the situation shown in Fig. 6, existing robotic technologies can predict the locomotion of pedestrians and control the vehicle for smooth collision avoidance. On the other hand, in the situation shown in Fig. 7, the observed path of the pedestrian in front does not appear to cross, and he would change his route after a while. If the vehicle kept on moving until the pedestrian in front changed lanes, the situation would become so dangerous that the vehicle might need to make an emergency stop. Emergency stops are a severe problem for welfare mobility aids, though they are not so critical for unmanned robots. Such emergency stop would not be accepted even from surrounding traffic participants, because usual traffic participants can estimate such situations and deal with them easily. The key point is evaluation and prediction from the view point of usual traffic participants.

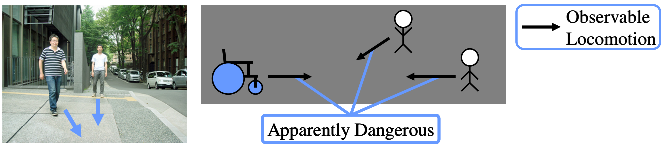

Fig. 6. Apparently Dangerous Situation

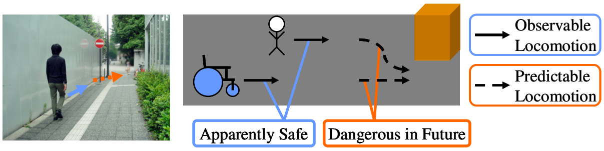

Fig. 7. Apparently Safe but Potentially Dangerous Situation

Thus, for the purpose of predictive autonomous locomotion based on interpersonal contexts, this research developed the algorithm for interaction prediction of surrounding pedestrian based on the relation of their position and velocity, and the algorithm of velocity control. Based on the knowledge about the personal space [5] of pedestrians, the system utilizes prediction of future proximity for its velocity control and makes sufficient margins for safely avoiding other traffic participants. Fig. 8 shows the schematic of the system. At first, the system senses the positions of surrounding traffic participant and obstacles, and the velocities of them. Then, the system estimates the margin time for surrounding traffic participant to change locomotion, and calculates the future proximity at that time. Based on those values, the system controls current velocity for making enough margin space for safely avoiding after a few seconds. The details of the system are described in our previous paper [7]. As a brief result, this system was able to start adjusting the future proximity by active velocity controls about five seconds before the surrounding traffic participant changed the lanes. For dealing with traffic flow smoothly as a usual traffic participant, expanding target situations of prediction is necessary for the next step.

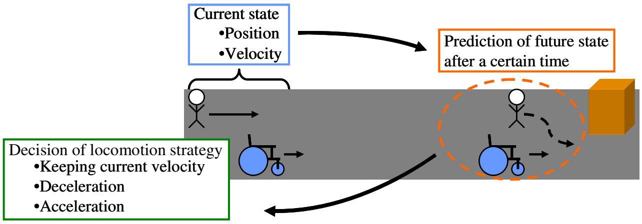

Fig. 8. Schematic of Interactive Control of Velocity Based on Prediction

3.3 Interactive Collision Avoidance Based on Surrounding Mobility Type

On the real pedestrian areas, there are various kinds of traffic participants such as pedestrian, wheelchair users and bicycle riders. They have different locomotion priorities in accordance with their social characteristics and mobility abilities. Thus, consideration of locomotion priorities based on surrounding mobility type is important for harmonious autonomous locomotion. Therefore, this research developed the algorithm of interactive collision avoidance based on surrounding mobility type. Fig. 9 shows the schematic of the interactive strategies. For wheelchair users and slow pedestrians, the vehicle changes lanes to avoid them autonomously when they face each other on the sidewalks. On the other hand, for bicycle riders and fast pedestrians, the vehicle decelerates autonomously with the aim of being passed by. Slow pedestrians are assumed as the elderly, while fast pedestrians are assumed as the healthy young. These interactive strategies would be effective for safe locomotion because active avoidance of traffic participants who has better locomotive abilities can make less risky situations of avoidance. In addition, the strategies would be also effective for acceptable locomotion because they conform the implicit orders of social and attitudinal priorities.

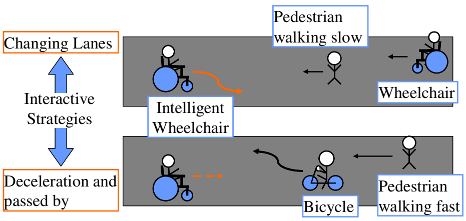

Fig. 9. Schematic of Interactive Collision Avoidance

To realize such interactive collision avoidance, this research developed the classification method of surrounding mobility type. Fig. 10 shows the sequence for mobility type classification. This system classifies the mobility type of an oncoming traffic participant mainly based on the image recognition though the system also uses LIDAR data to get information about position and size of him. Based on the estimated position and size of the oncoming traffic participant, the system extracts the captured image of him. Using the jointHOG detectors [8] of each mobility type, the system calculates the similarity point of the extracted image. Furthermore, in order to reduce the differences of the detecting capability of each detector, the component normalizes each result of moving average with linear discriminant functions. Based on the velocity and the comparison results of the normalized similarity points, the component classifies the mobility type of the detected traffic participant. The accuracy of this classification system in the preliminary experiment was over 80 % at the distance of 9.0m, which was enough far to avoid each other smoothly in an acceptable manner. As the result, the system recognized four kinds of mobility types; young pedestrian, old pedestrian, wheelchair user and bicycle rider, and executed two kinds of interactive collision avoidance; changing lanes for avoidance and deceleration for being avoided. By enhancing the classification system for much more various traffic participants, this system would be improved enough to realize acceptable locomotion. Furthermore, in some other aspects, this research thought that this system achieved human-machine collaborative avoidance, though human did not mean the rider but surrounding traffic participants. In addition, human-machine collaborative technologies like this system would realize interactive safety technologies of locomotion.

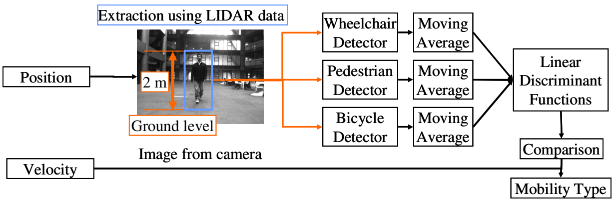

Fig. 10. Sequence for Mobility Type Classification

4 Conclusion

The objective of this study was to develop intelligent welfare mobility aids which had harmonious autonomous locomotion functions for the purpose of continuous outing of the elderly. At first, this research coordinated the concept of harmonious locomotion, and proposed the autonomous locomotion based on the interpersonal context. Then, this paper explained the following technologies briefly.

- Velocity control based on interaction prediction of surrounding pedestrian
- Interactive collision avoidance based on surrounding mobility type

The method of sharing interpersonal contexts focused mainly on the stand-alone sensing systems in this research. However, collaboration system using the telecommunication would be effective. For example, vehicle-to-vehicle and vehicle-to-pedestrian communication system utilizing smartphones would realize the much more interactive autonomous locomotion based on more precise personal information. By developing various applications of utilizing interpersonal contexts, we aim to realize harmonious autonomous welfare mobility aids.

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