Driving Intention Assistance for Front-wheel-drive Personal Electric Vehicle

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***Abstract*—Indoor personal electric vehicle "STAVi" was developed to reduce the burden of moving for elderly people in the progress of the aging population in Japan, in order to improve their quality of life. The STAVi is a front-wheel-drive EV which is operated through an 8-directional joystick by the driver. However, the over-steering caused by two rear caster wheels leads to unstable vehicle dynamics and difficult to control in some driving scenarios. This paper presents a novel Lidar SLAM based driving intention assistance algorithm which employs Line Segment Matching SLAM technique for fast SLAM matching for indoor scenario. Line Segment Matching provides more accurate result than the conventional corner-based Scan Matching. Model Error Compensator (MEC) is used in our feedback controller to assist STAVi moving correctly by driving intention. Real indoor experimental results show the effectiveness of the proposed algorithm.**

Keywords—personal mobility; STAVi; SLAM; Driving Assistance System; MEC; Autonomous robot;

I. Introduction

Japan's elderly population has rapidly grown to 24.1% of the total population in 2012 and with projections to 33.4% in 2035 [1]. Personal mobility systems and electric wheel chairs are used by elderly to reduce their burden of everyday transportation. Personal vehicle "STAVi" was developed by Sanwa-Hitech Co. Ltd [2] (Fig.1). The STAVi has some characteristics that can be used in the field of welfare. Elderly and handicapped people can easily access (to get on, to get off) the STAVi and the seat can be shifted up and down to provide better eye-line and to reach higher places easily. With the help of this personal mobility tool, elderly and handicapped people are able to greatly improve their quality of life.

Our goal is to build an intelligent driving assistance system based on the STAVi platform to help driver drive safely and smoothly. To achieve this goal, several sensors and controllers are installed on STAVi, including a Hokuyo Lidar range finder (LRF) in the lower frontal bumper, a Kinect 2.5D image sensor on the top of frontal chassis and two ultrasonic sensors in the rear bumper positions. LRF is used for building the mid-range environment map and collision avoidance. Kinect is employed to detect, recognize and track the specified target

like a pedestrian, leading STAVi or docking station. Rear ultrasonic sensors are used to avoid rear collision.

The STAVi is a front-wheel-drive EV which is operated through an 8-directional joystick by the driver. However, the over-steering caused by two rear caster wheels leads to unstable vehicle dynamics and difficult to control in some driving scenarios. This paper presents a novel Lidar SLAM based driving intention assistance algorithm which employs Line Segment Matching SLAM technique for fast SLAM matching for indoor scenario. Line Segment Matching provides more accurate result than the conventional corner-based Scan Matching. Model Error Compensator (MEC) is used in our feedback controller to assist STAVi moving correctly by driving intention. In MEC, instead of initial sensor, we use the yaw rate and velocity data estimated from SLAM as feedback to control the movement. Real indoor experimental results show the effectiveness of the proposed algorithm.

The paper is organized as follows: Section II quickly reviews STAVi and gives the over-steering characters; MEC controller design concept and our driving intention assistance control strategy are described in Section III. Section IV provides previous works in Lidar SLAM and our Line Segment Matching algorithm. Section V shows implementation details and experimental results.

Figure 1. Personal electric vehicle "STAVi"

II. Characteristics of Personal Vehicle "STAVi"

The front-wheel-drive STAVi is designed for elderly and handicapped people. It uses two rear free caster wheels to make a flat rear deck. This design is considered that driver can easily access from bed or wheel chair. STAVi also has a movable seat that can be shifted up and down. A driver controls the STAVi through an 8-directional joystick.

However, the over-steering caused by two rear caster wheels leads to unstable vehicle dynamics and difficult to control in some driving scenarios [5], for example, driver always needs to adjust the joystick direction even when going straight. Characteristic of over steering on flat floor is shown in Fig. 2.

To overcome the over-steering problem of STAVi, Model Error Compensator (MEC) is used in our feedback controller to assist STAVi moving correctly by driving intention.

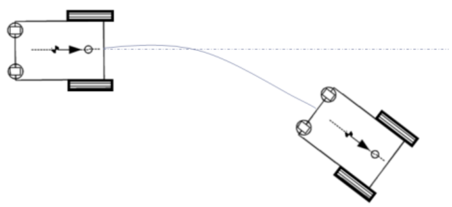


Figure 2. Over steering characteristic

III. CONTROL BLOCK WITH MEC

As described above, STAVi has the characteristic of over-steering. Since STAVi's self weight is only 250 lb, the vehicle dynamics is variable when loading different drivers, which makes the vehicle difficult to operate, even on a flat road. Therefore the traditional feedback controller like PID controller cannot provide a good performance. Instead of attempting to minimize the effects of the disturbance as in the robust filters or to decouple the disturbance as in the unknown input observers, it is proposed to estimate the disturbance estimation is used to reduce the model error and thus to improve the state estimation. This technique is denoted as model error compensator (MEC) [8].

A. Controller interface

STAVi is operated through an 8-directional joystick as shown in Fig. 3. Moving the stick along X-axis controls rotation angle and moving along Y-axis controls vehicle speed. For example, pushing the stick forward will move the vehicle go straight forward and pushing the stick toward left side will make the vehicle turn left in the same location. Joystick position will be converted to the input voltages in both speed and direction to the controller box.

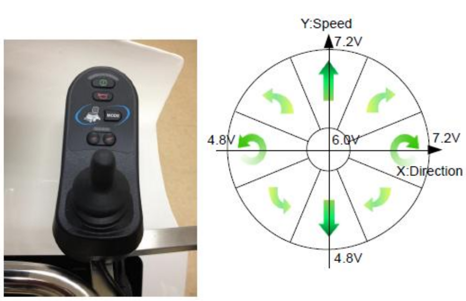
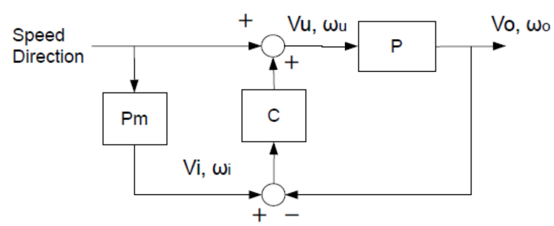


Figure 3. Joystick controller

B. MEC controller design

As described in Section II, STAVi has the over-steering characteristic and need to assist even for moving straight on a flat surface. However, since STAVi system dynamics is variable with different drivers, we need a simple and powerful controller to reduce the model error. MEC is an ideal controller for this purpose. With the input of plant output and ideal model output, MEC is able to control the system overall output to get closer to the ideal output.

To compensate the dynamic model change and disturbance of input observers, a novel MEC feedback controller is proposed. Figure 4 shows the controller block with MEC. Regarding to MEC concept details, please refer to [8].



Speed, Direction : input voltage from joystick operation
Vu, ω_u : control to STAVi motor
P : plant - STAVi
V_o, ω_o : observation of velocity and angular velocity with SLAM
C : PI controller
V_i, ω_i : ideal velocity and angular from ideal model.
P_m : ideal dynamic model

Figure 4. MEC Feedback Controller

Pm is the ideal dynamic model which is estimated by experiments of driving on a flat floor. Real velocity and angular velocity are subtracted from the ideal velocity and angular velocity. The subtracted value is inputted to PI controller C. The controlled value is added to input value of speed and direction.

Status equation is shown like follows:

$$V_u = K_{vp}(V_i(1-\exp\frac{-t}{\tau_v})-V_o)+K_{vi}\int(V_i(1-\exp\frac{-t}{\tau_v})-V_o)dt+S$$

$$\omega_u = K_{\omega p}(\omega_i(1-\exp\frac{-t}{\tau_\omega})-\omega_o)+K_{\omega i}\int(\omega_i(1-\exp\frac{-t}{\tau_\omega})-\omega_o)dt+D \tag{1}$$

Where, S and D are joystick input value for speed and direction control. τv, $\tau \omega$ is integration delay time for PI control. Vo, ωo are estimated by SLAM shown in the next section.

IV. LINE SEGMENT MATCHING SLAM

In the previous section, observation of velocity and angular velocity in the MEC feedback controller block diagram could use sensor output from the odometer and gyroscope or yaw rate sensor. However, all these local measurements need to be integrated in order to obtain the position and track. Large accumulated error cannot be avoided while driving a longer distance or continuous turning.

Simultaneous localization and mapping (SLAM) is an alternate solution which uses Lidar, vision or fused sensor to obtain a continuous obstacle map as well as own localization. Many approaches have been proposed for the last several decades [3][4][6][7]. To estimate the vehicle position, an internal sensor is generally used also known as dead reckoning.

However, using only odometers to estimate the position of the vehicle causes a stack of error due to a slipped tire on a slope and rough road.

To reduce this stack of error, external sensor such as the LRF enables to estimate SLAM accurately. On the contrary, if the external sensor extracts very few landmarks, ambiguity of matching positions between continuous frames will lead to a big error. In indoor environment, we have confirmed that line-based scan matching approach is more efficient than corner-based one. Because the corner-based scan matching is difficult to extract the feature point. Line-based scan matching algorithm is shown in Figure 5.

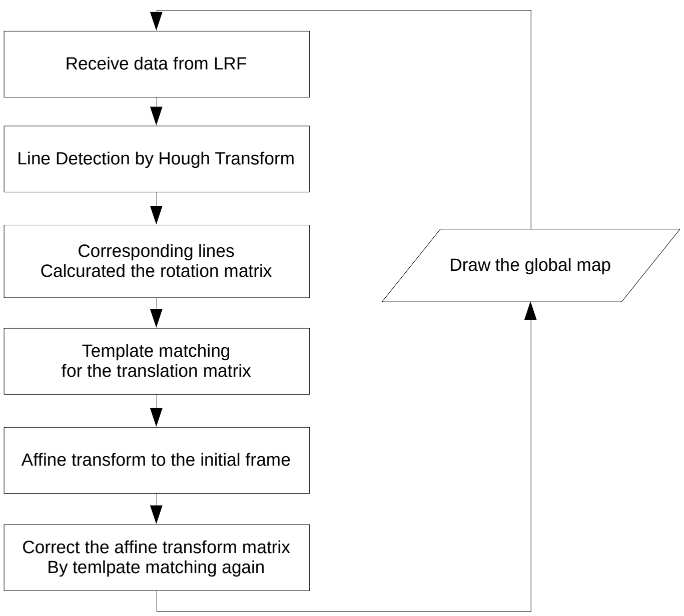


Figure 5. Line-Matching SLAM

1) Line Detection:

The equipped LRF, Hokuyo UTM 30-LX, has the maximum detection distance of 30m, scanning angle from -135° to 135° with the resolution of 0.25°. The received range data will be converted to scan image at 20mm/pixel resolution. Line segments are extracted from scan data by Hough transform. Each segment has its property descriptions like length, orientation, center position, end point.

2) Line Segment Matching for Rotation Calculation

Center position, orientation and length are used to match these line segments between two consequential frames. Figure 7 shows the detected and corresponded lines in frames. Vehicle rotation between two consequential frames is calculated by the average of orientation differences between matched line segment pairs.

3) Template matching for Translation Calculation

To calculate the translation matrix, we use template matching technique to find the best matching between the rotated frame and the previous frame. Searching region size depends on vehicle speed and orientation. We use a simple Kalman filter to predict vehicle's position and its variance to act as start position and searching region for template matching.

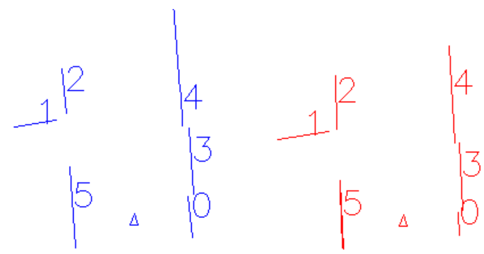
4) Affine Transform for Merging Maps

After calculating rotation and translation matrix, the new frame will be merged to the previous frame to build a continuous map through Affine transform. Figure 7 shows the merged map result.

5) Building Global Map

To avoid accumulated Affine transform error, the merged map in step 4) will be matched with the previous global map by template matching and the rotation and translation matrix are refined in this step. An example of global SLAM map result is shown in Figure 8.

In this way, the proposed SLAM algorithm generates a global obstacle map and its own track, meanwhile, the position and attitude angle are also estimated for Vo, ωo of MEC controller feedback control described in Section III.



(a) Previous frame (b) New frame

Figure 6. Detected and corresponded lines

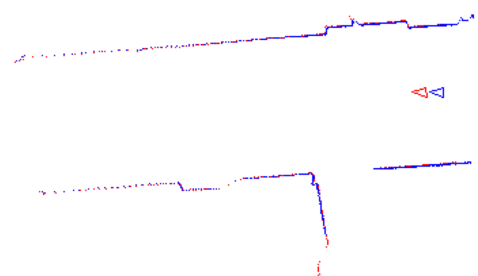


Figure 7. Merged map by template matching where blue points are previous frame data and red ones are new frame data

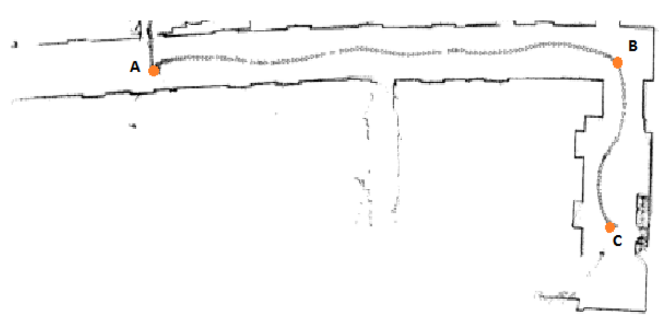


Figure 8. Global SLAM map result example

V. EXPERIMENTAL RESULTS

A. *Vehicle Control System Description*

STAVi control system block diagram is shown in Figure 9. Joystick module is connected to the R-Net Input port and R-NET Outputs control signal to the R-Net power module which generates the driving force to STAVi's left/right motors. A switch is used to switch manual/autonomous operation mode. Autonomous mode connects a tablet PC to the R-Net IOM through RS-232 port.

B. *Line Segment Matching SLAM Result*

To compare the proposed Line Segment Matching SLAM algorithm with the corner-based SLAM algorithm, several indoor experiments were carried out. Example result is shown in Figure 10. Since indoor environment does not provide enough corners and false corners by the occlusion problem, Corner-based scan matching suffers from the mismatching problem. Therefore, the proposed line segment matching SLAM algorithm shows its advantages in indoor environments.

To evaluate the quantitative measurement error of proposed line segment matching SLAM, we compared the measurement between manually measured result with our SLAM output for both translation and rotation matrix. In Figure 8, distance from point A to B is 24 m by manually measurement and SLAM result is 23.91 m, which gives the measurement error is 9cm (0.305%). From point B to C is 5.6m by manual measurement and our SLAM result is 5.55 m, therefore the measurement error is 5cm (0.169%). In Figure 11, the rotation measurement error is 1.5 ~ 3 degrees.

In Figure 12, the translation measurement error happens because of the two parallel of long line segments on the corridor that is disabled to make a distinction of moving forward or backward.

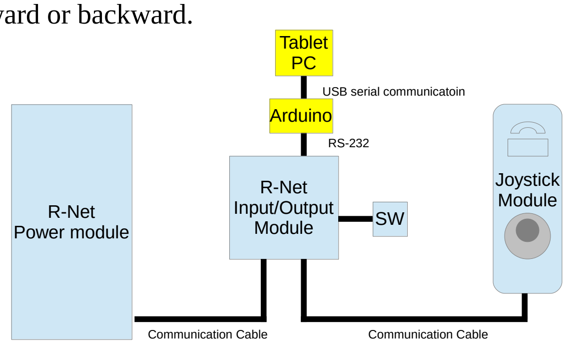
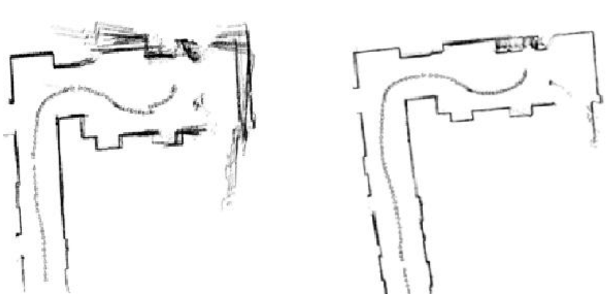


Figure 9. The experimental apparatus



(a) Corner based (b) Line Segment based

Figure 10. Comparing SLAM result

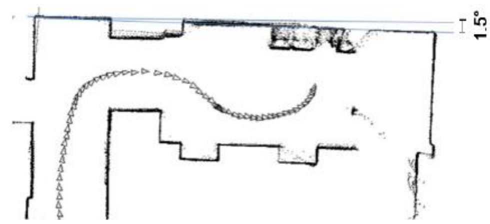


Figure 11. Line Segment Matching SLAM rotation error

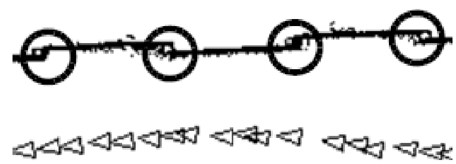


Figure 12. Line Segment Matching SLAM translation error

C. *MEC Controller Design*

In order to obtain the ideal response between joystick input and motor output, we measured the STAVi transient response value (speed and angular velocity) based on joystick's 11 steps of directional input (from -50 degrees to 50 degrees) and 11 steps speed input (from 10 to 110). Test results are shown in Table 1 (STAVi speed output) and Table 2 (STAVi angular velocity output). Delay time constants are also measured and the average time constant is adopted for the design of ideal first order lag system. All measurements are taken by our SLAM system.

In Table 1 (real angular velocity), when the input value is 60 of the Direction against the Speed, the angular velocity is not zero. From the real dynamics (Table 1), we create an ideal dynamic model (see Fig. 13.). The error between the real and ideal model is added to the input.

Table 1. Transient response of STAVi velocity

Direction / Speed	-50	-40	-30	-20	-10	0	10	20	30	40	50	Average
80	20.2	-	13.7	8.6	10.2	9.1	7.8	11.2	-	-	20.7	12.7
90	26.8	23.7	19.2	17.6	17.0	15.5	15.5	16.6	17.0	21.1	25.8	19.6
100	24.4	29.8	29.9	23.6	25.3	21.6	23.9	25.5	23.5	22.0	-	24.9
110	26.2	32.9	35.9	33.4	33.5	32.6	30.1	32.3	30.6	32.7	33.2	32.1

Table 2. Transient response of STAVi angular velocity

Direction / Speed	-50	-40	-30	-20	-10	0	10	20	30	40	50
80	57.7	-	32.9	12.8	4.1	0.1	-1.9	-12.9	-	-	-59.5
90	80.5	63.5	44.3	23.1	8.0	2.8	-4.6	-14.4	-34.8	-54.0	-64.7
100	57.8	60.1	57.7	31.7	11.9	1.4	-5.1	-23.0	-34.5	-63.0	-
110	62.0	60.5	60.4	38.4	24.9	3.6	-10.4	-21.7	-40.0	-61.9	-62.9
Average	64.5	61.4	48.8	26.5	12.2	2.0	-5.5	-18.0	-36.4	-59.6	-62.3

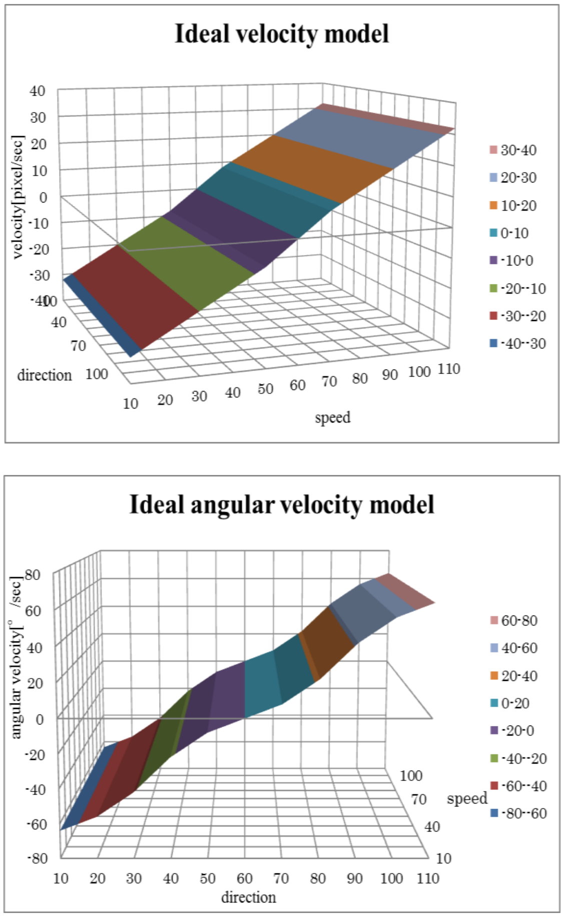


Figure 13. Ideal dynamic model

In PI controller, the proportional gain K_{vp} and $K_{\omega p}$ and integral gain K_{vi} and $K_{\omega i}$ for input driving force are given by the following.

$$\begin{aligned} K_{vp} &= 2.0 \\ K_{vi} &= 0.7 \\ K_{\omega p} &= 2.0 \\ K_{\omega i} &= 0.7 \end{aligned} \qquad (2)$$

The optimal value is calculated by experiments. In the next section, the results by using this feedback controller are shown.

D. Driving Intention Assistance results by SLAM

Figure 14 Shows the trajectory of STAVi movement along a straight line on a flat floor. On the left side, it is with no control and right side is with control. As you can see, with the control there is an improved straightness trajectory by comparison with no control. The significant smoothness and efficiency helps driver driving with their intention.

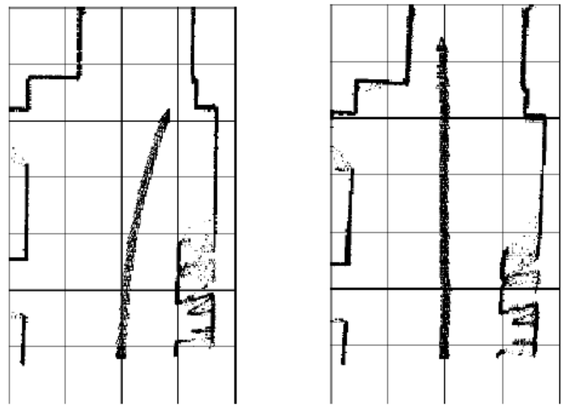


Figure 14. Without MEC controller and with MEC (grid interval : 1m)

VI. Conclusion and Future work

Feedback from SLAM is proposed to control for indoor personal vehicle STAVi with our novel MEC controller. The Line matching SLAM approach is more efficient than corner matching SLAM for indoor environment. We developed the ideal dynamic by referenced experimental real dynamic. The STAVi becomes ideal dynamic model which has no over steering characteristic. It enables driver to control easily and no need to adjust the direction when going straight.

In the future work, the autonomous vehicle will be produced using SLAM. Adding, we are developing path planning and recognizing obstacles and avoiding system. Furthermore, to be more intelligent vehicle we try to build a 3D map using Microsoft Kinect which enables STAVi to understand the environment accurately for precise control.

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