Outdoor waypoints navigation for intelligent wheelchair by using Differential GPS and INS

Yoshihiro MIYAZAKI. Mitsuhiro IMAMURA. Reo TOMITAKA.
Kazuyuki KOBAYASHI. Kajiro WATANABE
HOSEI University ,3-7-2 Kajino-cho Koganei Tokyo 184-8584 , Japan
yoshi@k.hosei.ac.jp

***Abstract*—Because of rapidly growing the aging society in Japan, development of wheelchair for elderly people will necessary. In order to develop wheelchair for elderly people, intelligence is prerequisite, to assist appropriate safety driving. This paper describes a development of intelligent wheelchair for elderly person, which can autonomously assist outdoor multiple-waypoints driving. In order to realize such functionality, we employ differential GPS and INS sensors with laser rangefinder. To confirm the validity of proposed method, we examined by outdoor experiments.**

Ⅰ. INTRODUCTION

Electric wheelchairs are important tools to aid in the mobility of disabled and/or elderly persons [1]. Because of the rapid growth in the elderly sector of Japanese society, greater demand for an intelligent wheelchair is expected [2]. The mobility of wheelchair users is restricted by the condition of the surface the wheelchair travels on, which may include obstacles or bumps. For elderly persons, an intelligent wheel chair must be user independent and prevent fatigue without necessitating difficult joy-stick driving especially in common outdoor public environments where passengers and/or obstacles are present.

The purpose of this study is to find most appropriate driving course that will prevent the collision of the wheelchair with such impediments. In order to prevent dangerous situation in driving, we have developed an intelligent wheelchair which is equipped with various types of sensors to enhance the wheelchair's mobility, especially in outdoor environment.

To confirm the validity of the proposed developed intelligent wheelchair, we modify the vehicle that satisfies the regulation of 12th Intelligent Ground Vehicle Competition (IGVC). In the IGVC, waypoints navigation called a navigation challenge. The competition of a navigation challenge is how to navigate the ground vehicle autonomously travel from a starting point to a number of target destinations and return to home base only the information of the target coordinate. The coordinates are given in latitude and longitude as well as the spans on an x-y grid. Construction barrels, tree and light poles are located on the course in such positions that the waypoints navigation vehicle must circumvent to reach the waypoints. Photo. 1 shows typical waypoints and used construction barrels.

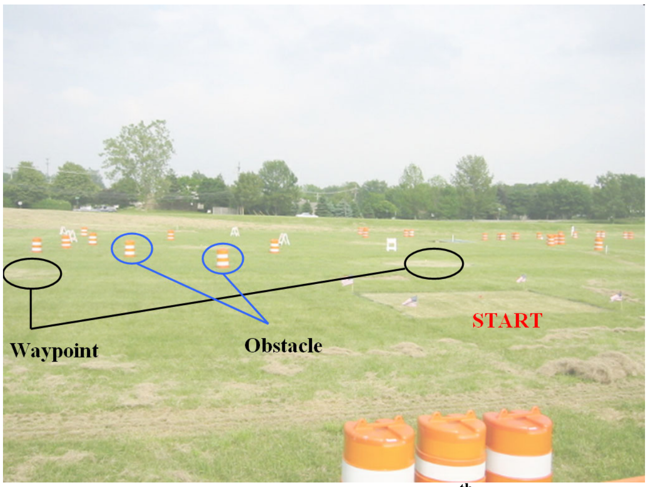

Photo.1 Navigation Challenge in 12th IGVC

A. The detailed rule of navigation challenge in IGVC

The competition course will be prepared on a golf course like bumpy ground approximately 45 by 70 meters, and the total travel distance of the course will be on the order of 220 meters depending on the route for waypoints. Fig.1 shows a sample of waypoints map, which is provided by competition organizer. Only a number of target points where the vehicle must pass were given. The circle mark stands for the target waypoint. There are no standup markers to indicate the target positions while competition. The vehicle must pass within 2 meters of a target waypoint. The target points of x-y coordinates as well as latitude and longitude coordinate information are given for autonomous waypoints navigation.

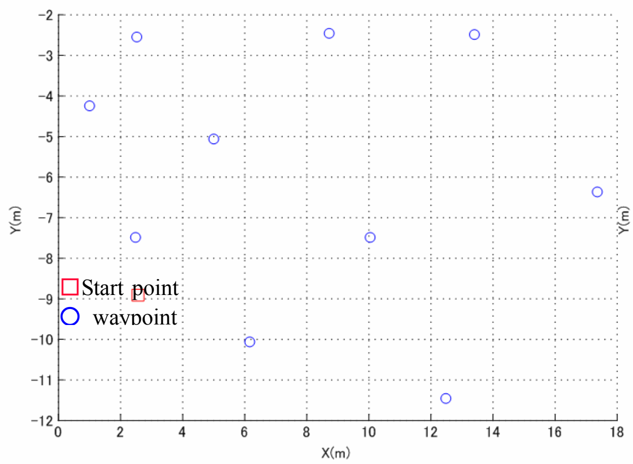

Fig.1 A sample of waypoints map 2004

Ⅱ. PROPOSED SYSTEM

Photo.2 Autonomous waypoint navigation vehicle

Photo.2 shows an autonomous waypoint navigation vehicle which is based on a commercial electrical wheelchair, model MC16P, manufactured by SUZUKI Co. in Japan. The wheelchair has two differentially driven rear wheels while the front wheels have power steering capabilities. It is powered by two 12 V batteries (35 AH) and reaches a maximum speed of 6 km/h. The wheelchair can be manually steered by a standard joystick. The core of developed intelligent navigation hardware is a notebook type PC (Pentium 4 running at 1.6GHz) powered by the Windows-MATLAB environment. The developed intelligent wheelchair employs three types of sensors:
(1) A global positioning sensor (a Differential GPS).
(2) A local positioning sensor which is a combination of a dual differential speedometer and optical fiber gyroscope.
(3) An environmental sensing device (A laser rangefinder).
The configuration of these sensors is depicted in Figure 1.

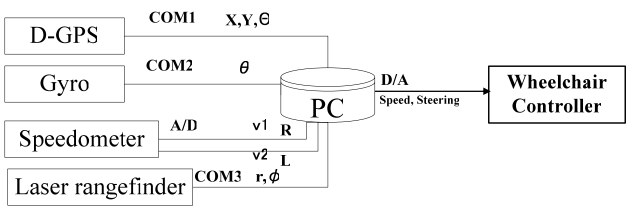

Fig.3 Waypoint Navigation System architecture

The DGPS is used to estimate the current self-position and the trajectory to waypoints. Update rate of the DGPS signal is about 0.05 second and the accuracy is about ±0.5 meters. However, depending on geometrical condition of GPS satellites, position from DGPS signal is not always reliable. In order to compensate the problem above, we fuse the DGPS information and optical fiber gyro information, from which we can estimate absolute position and direction of the vehicle continuously.
Dead-reckoning is a well-known local positioning method which uses a speedometer and angular sensor in wheeled vehicles. The problem associated with the dead-reckoning method is measurement drift error caused by integration. In order to compensate for drift error, a multiple-sensing device, a geographic information system, and the Differential Global Positioning System (DGPS) have been introduced in a coherent system.

A. Systems and Problem description

In order to demonstrate outdoor navigation, we adopt the following assumptions:
A1) The outdoor ground can be consistently flat.
A2) The dynamic model of the vehicle can be simply approximated by a two-wheel steering model.
A3) Selected waypoints are pre-determined by the user. In this study, we did not take into account a situation in which it was not possible to drive a conventional wheelchair.
The problems considered here are:
P1) How to navigate safely without collision.
P2) How to navigate a prescribed course according to several prescribed waypoints.
To solve these problems, we apply the Kalman filtering technique to fuse various types of sensing information such as that produced by differential-GPS, laser rangefinders, and INS sensors in order to navigate accurately and safely without collision.

B. Variables and constants for the proposed system

The variables and constants of the proposed waypoint navigation system shown in Figure 1 are defined as follows:

[Common variables and Constant]

k : Discrete time
τ : Sampling interval
v : Speed of the vehicle

[Differential-GPS]

X_g, Y_g, Θ_g x-y absolute position and absolute direction of the vehicle

[Dead-reckoning]

$x_{dr}, y_{dr}, \theta_{dr}$ x-y local position and relative direction of the vehicle

[Kalman filter]

$z(k)$: State vector
$F(k)$: System matrix
$G(k)$: System noise weight matrix
$\omega(k)$: System noise vector
$m(k)$: Observation vector
$H(k)$: Observation matrix
$\upsilon(k)$: Observation noise vector
K_k : Kalman gain matrix
$\hat{x}_{k|k}$: Estimate value of x_k at $k\tau$
$\hat{x}_{k+1|k}$: Estimated position vector x_k at $(k+1)\tau$

[Path planning]

x, y, θ : Absolute position and angle of the vehicle
$\dot{x}, \dot{y}, \dot{\theta}$: Derivative of x, y, θ with respect to time
x_0, y_0, θ_0 : Initial vehicle position and direction
x_n, y_n, θ_n : Target position and direction

Ⅲ. SENSORS AND ESTIMATION OF THE SELF POSITIONING

A. Differential-GPS

One of the most popular navigation systems employs a GPS to determine the vehicle's position. GPS can be used anywhere in the world, is compact, and easy to use. For vehicle navigation guidance, the GPS is sufficiently accurate to within 10m. However, in order to drive autonomously, the GPS is not accurate enough. To improve accuracy, DGPS is an easy solution. In the DGPS, a fixed station receives signals from certain satellites. At the same time the moving platform whose position is to be determined receives the same signals from the same satellites in order to locate the relative coordinates. In the proposed system, we use a differential GPS signal and acquire X_g, Y_g, Θ_g as the real-time position of the vehicle.

B. Dead-Reckoning

Dead reckoning is the process of estimating a vehicle's position by advancing from a known position using angular velocity, wheel rotational speed, time, and distance to be traveled. In order to determine the vehicle's position by dead-reckoning, the wheel speed as well as the angular velocity of the vehicle must be integrated. Since angular velocity $\theta_{dr}(k)$ can be calculated from gyro scope. The x-y coordinate of the local position $x_{dr}(k), y_{dr}(k)$ can be given by

$$x_{dr}(k+1) = v(k)\cdot\tau\cdot\cos\theta_{dr}(k) + x_{dr}(k) \qquad (1)$$

$$y_{dr}(k+1) = v(k)\cdot\tau\cdot\sin\theta_{dr}(k) + y_{dr}(k) \qquad (2)$$

From (1) and (2), we can estimate the local coordinate and its orientation to the vehicle.

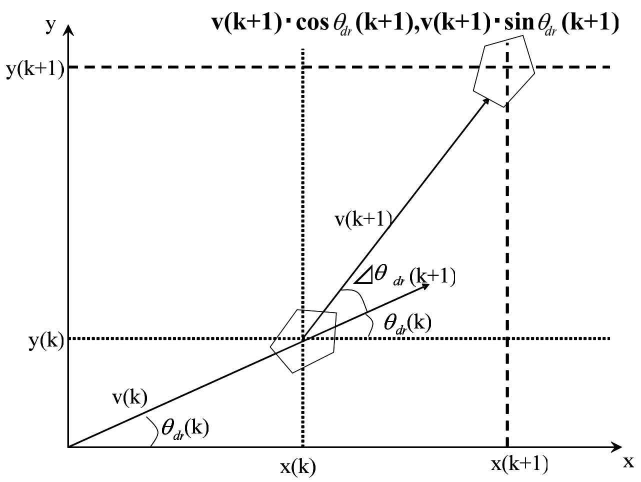

Fig.4 A model of Dead-Reckoning

C. Kalman filter

We propose a method that fuses the Differential-GPS and INS sensors by using a Kalman filter. The Kalman filter is a type of adapted digital filter and is intended to predict or estimate the true value based on a discrete time that involves errors. Kalman filtering is the most suitable technique to combine inertial and D-GPS measurements, but it requires adequate dynamics and measurement covariance models for the INS and D-GPS systems.
In order to apply the Kalman filter, we derive following discrete state space model.

$$z(k+1) = F(k)\cdot z(k) + G(k)\cdot\omega(k) \qquad (3)$$

$$m(k) = H(k)\cdot z(k) + \upsilon(k) \qquad (4)$$

where the vectors and matrices are defined as follows;

$$z(k) = [x(k) \quad y(k) \quad v_x(k) \quad v_y(k)]^T$$

$$F(k) = \begin{bmatrix} 1 & 0 & v(k)\cdot\tau\cdot\cos(\Delta\theta(k)) & -v(k)\cdot\tau\cdot\sin(\Delta\theta(k)) \\ 0 & 1 & v(k)\cdot\tau\cdot\sin(\Delta\theta(k)) & v(k)\cdot\tau\cdot\cos(\Delta\theta(k)) \\ 0 & 0 & \cos(\Delta\theta(k)) & -\sin(\Delta\theta(k)) \\ 0 & 0 & \sin(\Delta\theta(k)) & \cos(\Delta\theta(k)) \end{bmatrix}$$

$$m(k) = [x_g(k) \quad y_g(k)]^T$$

$$H(k) = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix}$$

$$\upsilon(k) = [n_x(k) \quad n_y(k)]^T$$

A flowchart of the self-position estimation method using a Kalman filter is shown in Figure 5.

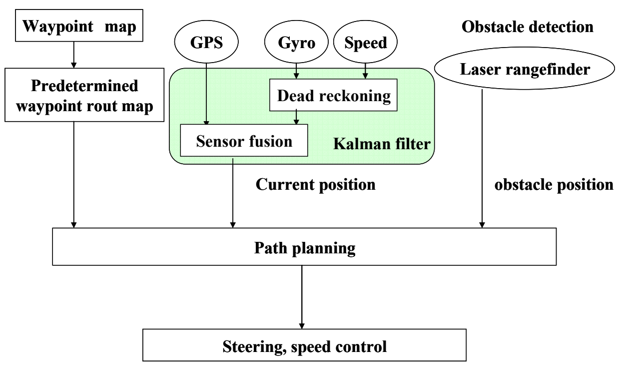

Fig.5 schematic diagram

Ⅳ. MEASUREMENT SYSTEM

A. Dynamic route planning

To generate a path for the vehicle in common outdoor public environments where passengers and/or obstacles are present, dynamically changed path generation is necessary.
Two different types of path planning decisions are de-fined in order to ensure accurate and safety navigation.
(1) Long-term route planning navigation
(2) Short-term route planning navigation,
Both of which are depicted in Figure 7.

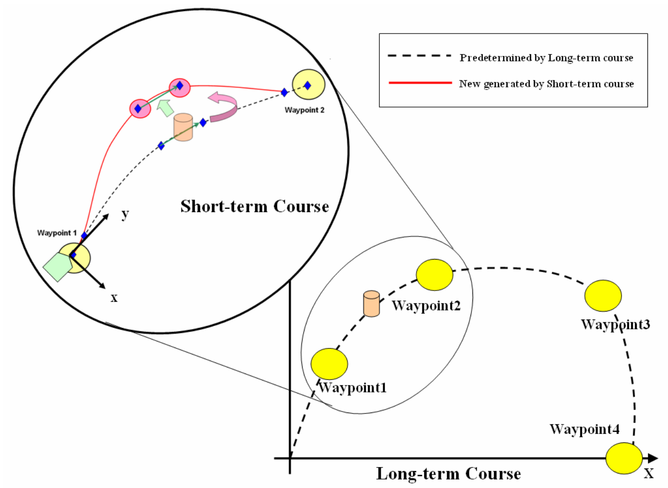

Fig. 7 Dynamic path planning method

Long-term route planning is a kind of traveling salesman problem which is aimed at allowing accurate and shorter distance of waypoint navigation. In order to generate a route for the vehicle, we use a cubic spline function to interpolate the path between the waypoints. Short-term route planning is intended to avoid collision with obstacles. Short-term route planning can dynamically change depending on the surrounding outdoor conditions. The path, which is generated by short-term route planning depending on obstacle position, generates two virtual waypoints and short term path to avoid obstacles. To navigate between the dynamic waypoints, a path tracking algorithm is employed in order to avoid collision during autonomous driving.

Ⅴ. EXPERIMENTS

In order to confirm the validity of proposed system, we participate 12th Intelligent Ground Vehicle Competition. The Competition ware carried out in Oakland University at MI USA.

A. Experimental results

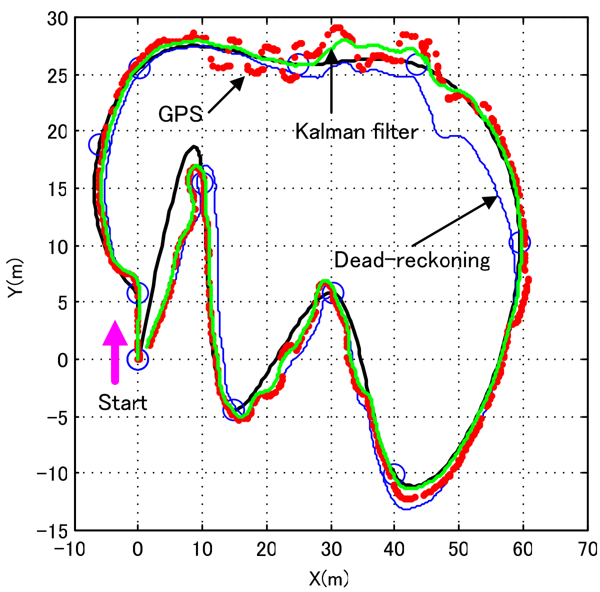

Fig.8 Result of experiment

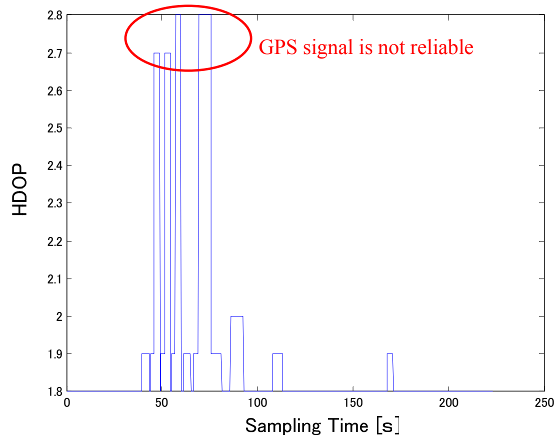

Fig.9 Not reliable GPS signal points

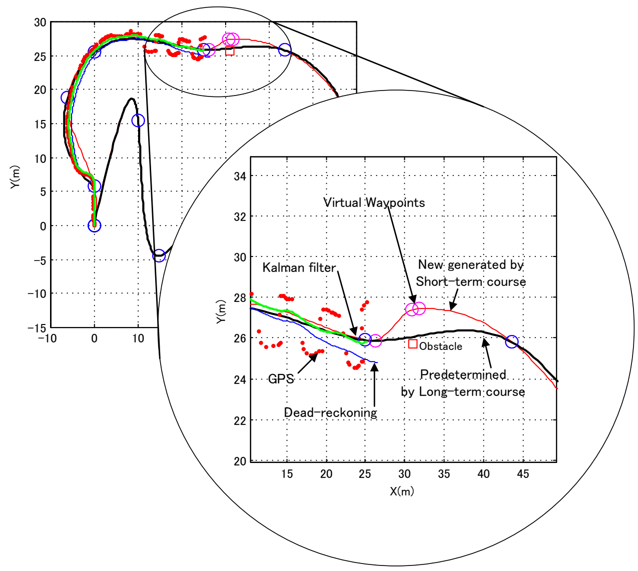

Fig.10 New generated course by Short-term

Ⅵ. CONCLUSION

This paper describes a development of the intelligent wheelchair that satisfies the regulation of 12th Intelligent Ground Vehicle Competition. In order to navigate the intelligent wheelchair, we employ combination of DGPS sensor and the optical fiber gyroscope and speedometer and a laser rangefinder. By using these sensors, we apply Kalman filter positioning estimation and obstacle detection by using range profile data. Depending on condition of obstacles, we apply long term path planning and short term path planning to generate most appropriate path for the wheelchair. The validity of the proposed method is verified by actual experiments and demonstrates smooth and safety navigation without encountering difficulties.

Finally, we should notice that we got first prize at navigation challenge in this year's competition in IGVC 2004 by using above proposed configurations.

ACKNOWLEDGEMENTS

This research was partially supported by the Ministry of Education, Science, Sports and Culture, Grant-in-Aid for Young Scientists (B),2004,No.15700381

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