Development of Dynamic Robust Human Tracking Algorithm for Human Following Intelligent Wheelchair

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***Abstract*--This paper describes the development of a dynamic, robust algorithm for tracking a walking human by an autonomous intelligent wheelchair. In order to follow a target individual, the proposed system employs a laser rangefinder and an omni-directional camera. The validity of the method was examined experimentally in practical environment.**

I. INTRODUCTION

Transportation services such as use of wheelchairs are usually carried out by nursing personal which pushes the patient or disabled person sitting. Since pushing and maneuvering a heavy wheelchair exposes the back of the pushing person to significant strain, these people often suffer severe long-term back problems. Using an autonomous intelligent wheelchair, which is able to follow the nurse side by side like a heeling dog, through arbitrarily populated, continuously changing natural environments would certainly allow the reduction of the problem or even avoid it.

In this paper we study the problem of coordinating the motion of an autonomous wheelchair and a human through a populated, continuously changing natural environment. This problem has a very useful application in the transportation of disabled or elderly people or the transportation of patients in a hospital and/or outdoor open space human crowed situation.

To follow a targeted human, many researchers developed and proposed based on vision sensor [1]-[3]. However, these approaches are not practical in the sense of reliability and robustness and are still under development.

In order to effectively follow a targeted human, robust image processing as well as advance sensor fusion techniques are required. An autonomous intelligent wheelchair with the ability to follow a human requires several basic abilities: recognition of the targeted individual, recognition of other humans and the environment around the wheelchair, and collision avoidance with other human as well as obstacles. In order to successfully achieve such goals, we employ robust image processing in the form of a template-matching technique, and advanced sensor fusion as a dynamic range adjusting human tracking technique. The validity of the proposed method is verified in existing practical human crowded environments.

II. PROPOSED SYSTEM AND PROBLEM DESCRIPTION

A. *Proposed system*

Figure 1 shows the configuration of the proposed autonomous intelligent wheelchair. Developed autonomous intelligent wheelchair is based on an electric wheelchair and employs an omni-directional camera as a no-dead angle vision sensor, and a laser rangefinder as a range profile sensor. The key feature of the proposed system is sensor alignment. The outputs of both the sensors are r-θ coordinates; thus, we vertically aligned these sensors to correspond with the angles of objects. Figure 2 shows the architecture of the hardware of the proposed autonomous intelligent wheelchair. The system is based on a commercial electrical wheelchair; model MC16P, manufactured by the SUZUKI Co. of Japan. The wheelchair has two differentially driven rear wheels and power-assisted steering wheels in the front. It is powered by two 12 V batteries and reaches a maximum speed of 6 [km/h]. The standard wheelchair can be manually steered by a joystick. The core of the hardware is composes of a notebook PC (Pentium 4 1.9GHz) as its on-board computer, powered by the Windows XP operating system with MATLAB/vcapg2.

Fig. 1. Configuration of proposed human following intelligent wheelchair

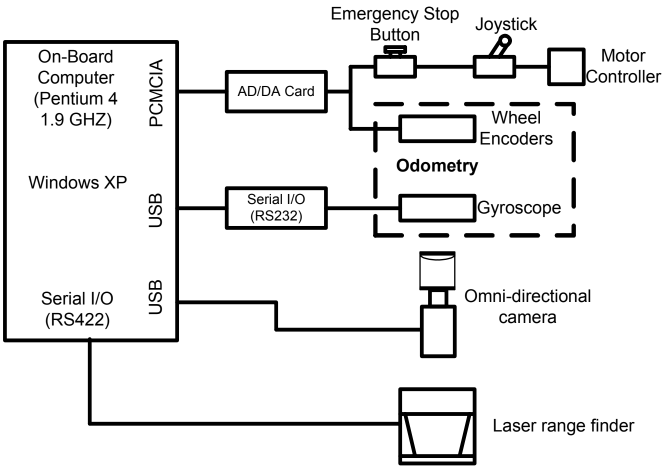


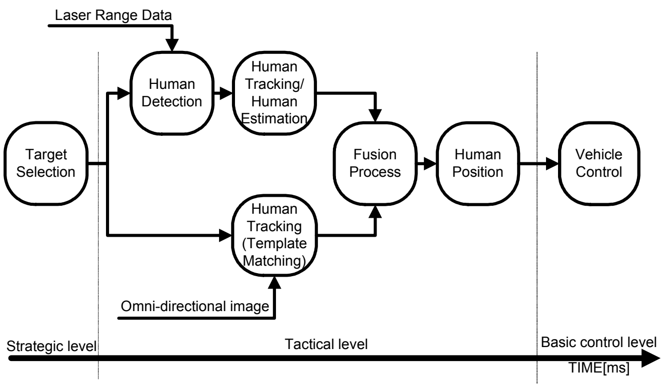
Fig. 2. Hardware architecture of proposed human following Intelligent wheelchair

The developed intelligent wheelchair is also equipped with a variety of sensors for perceiving its environment, for tracking a human, obstacles detection, and for position estimation. These include:

- An omni-directional camera with MATLAB/vcapg2 interface
- One SICK two-dimensional (2-D) laser range-finder LMS 200 with 500kbps RS422 interface.
- A dead-reckoning system consisting of a set of rear wheels rotation encoders and an optical-fiber based gyroscope.

These sensors are connected to, and communicate with, the laptop computer using a USB/PCMCIA/SERIAL bus, as shown in Figure 2. Motion commands for the intelligent wheelchair are sent over a PCMCIA DA card to the motion controller powering the wheel motors.

Figure 3 shows the software architecture of the proposed system. The abstract of the proposed algorithm consists of three component levels: target selection as strategic level, human detection and estimation by using a sensor fusion technique as a tactical level, and wheelchair control as a basic control level.



B. Assumptions

In order to successfully follow the targeted human, we make the following assumptions regarding the robust human detection algorithm as well as the human tracking algorithm.

(A1) The walking speed of the targeted individual cannot exceed the maximum speed of the vehicle.

(A2) Only static obstacles are taken into account.

This proposed system can avoid collision with multiple obstacles. Assumption (A2) is intended to simplify theoretical development.

C. Problem description

The problems considered here are:

(P1) How to fuse the laser range profile data and the omni-directional image to detect the human which the system intends to follow.

(P2) How to develop a robust targeted human detection algorithm.

III. HUMAN DETECTION ALGORITHM

A. Omni-directional image

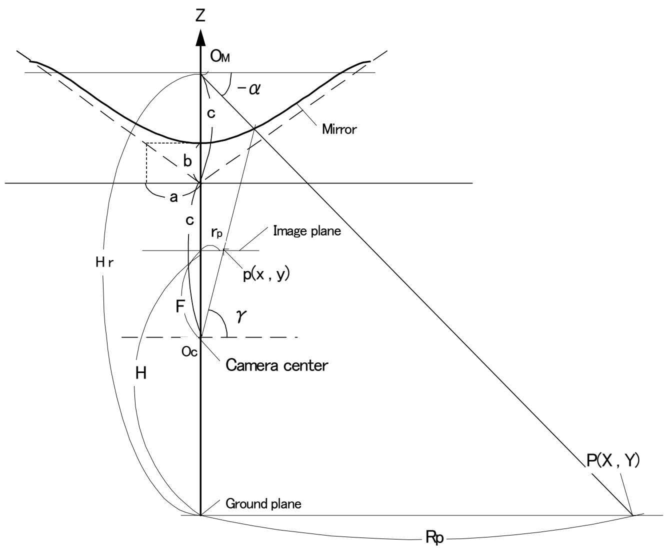


Fig. 4. The relationship between hyperbolical omni-camera's input image plane and ground plane

In order to detect the targeted human via the omni-directional camera, we define the following variables shown in Figure 4.

[variables]

(x, y) : x - y coordinates (for input image plane)

(X, Y, Z) :absolute coordinates (for ground plane)

f :focus imaging camera

a, b, c, α, γ :parameter which is determined by hyperboloid curve of mirror

H :distance from mirror to the ground

r_p :distance of image (input)

R_p :distance of ground plane (output)

The basic equation based on the geometrical relation between global ground coordinate and captured omni-directional image can be expressed by eq. (1), eq. (2) and eq.(3)

$$Z = \sqrt{X^2 + Y^2}\tan\alpha + c \tag{1}$$

$$\tan\alpha = \frac{(b^2 + c^2)\sin\gamma - 2bc}{(b^2 - c^2)\cos\gamma} \tag{2}$$

$$\tan\gamma = \frac{f}{\sqrt{x^2 + y^2}} \tag{3}$$

The omni-directional image is generally captured by the x - y image coordinate. The relationship between the r - θ coordinate as well as the global x - y coordinate can be calculated by using from x - y coordinate image to r - θ coordinate

$$r_p = \sqrt{x_{image}^2 + y_{image}^2} \tag{4}$$

$$\theta = \tan^{-1}\frac{y_{image}}{x_{image}} \tag{5}$$

Since the global coordinate of Z is constant, global X - Y can be calculated by using r - θ coordinate data.

$$R_p = \frac{(Z - c)(b^2 - c^2)r_p}{(b^2 + c^2)f - 2bc\sqrt{r_p{}^2 + f^2}} \tag{6}$$

$$X = R_p \frac{x}{\sqrt{x^2 + y^2}} = \frac{R_p}{r_p}x \tag{7}$$

$$Y = R_p \frac{y}{\sqrt{x^2 + y^2}} = \frac{R_p}{r_p}y \tag{8}$$

B. *Laser range profile*

The profile data from the laser rangefinder is acquired by the r - θ coordinate and can convert the global x - y coordinate by using following equations:

$$X = R_p \cos\theta \tag{9}$$

$$Y = R_p \sin\theta \tag{10}$$

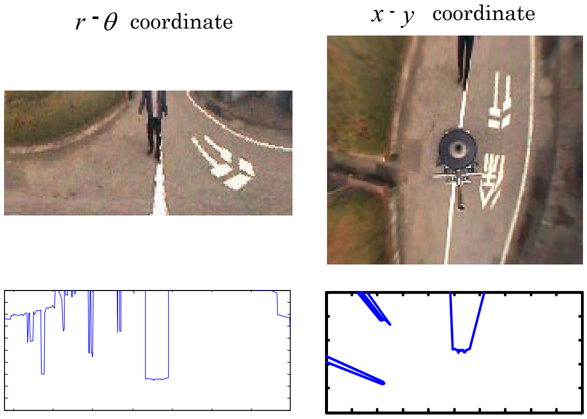


Fig. 5. Typical sample data with targeted human.

Figure 5 shows typical data sampled from the laser rangefinder and the omni-directional camera.

Figure 6 shows a typical sensor fusion image produced by r - θ projection. We can observe the targeted individual via both the laser rangefinder data as well as the omni-directional image.

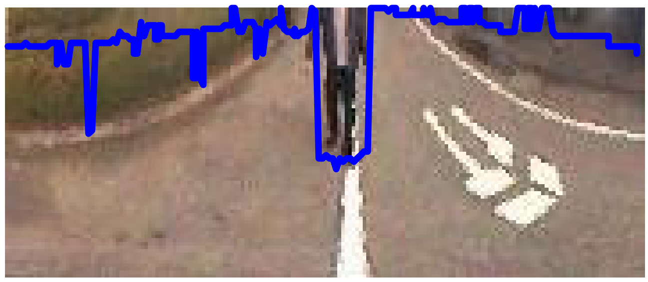


Fig. 6. Result of sensor fusion image by using r - θ projection

C. *Template matching*

The template matching technique can allow the intelligent wheelchair to follow the human despite his or her frequent changes in distance and the direction. Robust and highly accurate following is achieved by combining the wide angle, high-resolution measurement obtained by image recognition with the laser rangefinder's distance measurement. We applied a template matching technique described as follows:

$$R_{xy} = \frac{\sum_{x=0}^{s}\sum_{y=0}^{s} B_{x+i,y+j} \cdot T_{x,y}}{\sqrt{\sum_{x=0}^{s}\sum_{y=0}^{s} B_{x+i,y+j}^2 \cdot \sum_{x=0}^{s}\sum_{y=0}^{s} T_{x,y}^2}} \tag{11}$$

R_{xy} is the cross-correlation can be calculated by using FFT. where B and T are defined as gray scale images for the input image and temple image, respectively. The summations are carried out over the size s of the template image. The denominator in eq.(20) normalizes the result for variations in the overall brightness of the template image or the input image. The maximum normalized correlation value of R_{xy} is defined as plus one. Figure 7 shows sample data obtained using the template matching technique. Figure 8 shows a 2-dimensional cross correlation.

Fig. 7. Sample data with template matching technique

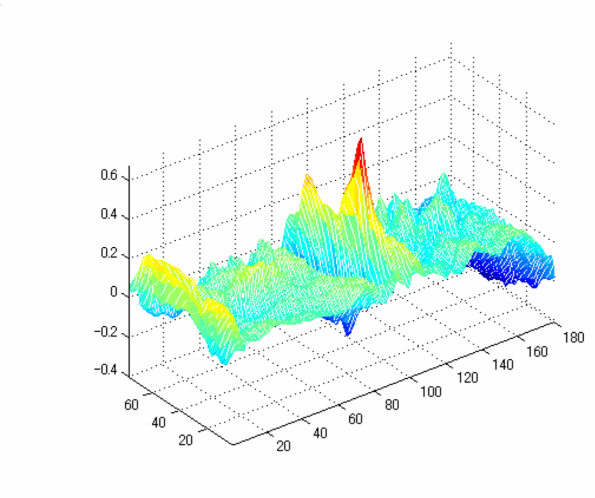


Fig. 8. 2 dimensional cross correlation value.

D. *Human Trajectory Estimation*

To eliminate the effect of false information produced by sensor noise, we apply Kalman filtering by which two different kinds of information from the omni-directional camera and laser range finder are fused. Detailed Kalman filter implementation is described in [4].

IV. Experiments

To verify the proposed algorithm, a human-tracking experiment was performed in an outdoor environment. The maximum walking speed of the target individual was about 2[m/s]. Because of safety issues, we set the stopping range between the target and the intelligent wheelchair at 1[m]. The initial distance between the target individual and the vehicle was about 1.5[m]. Figure 9 shows the trajectory of the human and the Intelligent wheelchair. The dotted line shows the trajectory of the target individual and the continuous line shows the trajectory of the Intelligent wheelchair. The trajectories correspond closely.

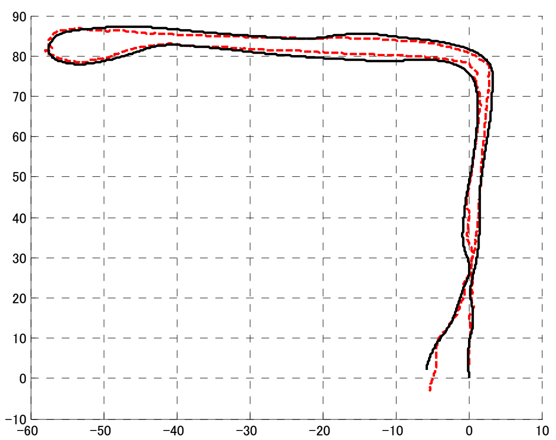


Fig. 9. Trajectory of human and intelligent wheelchair

V. Conclusion

In this paper, we propose a dynamic human tracking algorithm for an intelligent wheelchair capable of following a human target. The alignment of a laser rangefinder and an omni-directional camera allows a significant reduction of computational time for object recognition while still being able to detect a human target. The measurements obtained by the two sensors are fused and combined via the α-β type Kalman filter. The validity of the proposed method is examined experimentally.

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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