Silbo : Development Walking Assistant Robot for the Elderly Based on Shared Control Strategy

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Summary
In this paper we propose system architecture and implementation methodology of walking assistant robot for the elderly. We use shared control system based on sensor feedback. For operation user push or pull handle, than robot sense applied force. It decides velocity and direction of the robot. If obstacles are detected, robot avoids obstacles and plans new path for collision free. It can provide power assistance and safety for the elderly.

Key words:
robot, walking assistant, walking assistant robot, walking intent recognition.

Introduction

With the development of science and medical technologies, the economic growth and so on, many country (include Korea) is aging at the fastest rate[1]. The rapid aging of the population will cause problem for the nation.

The aim of this study is to development robotic assistant for the elderly. Cane, walker, wheelchair are general assistant equipments for the elderly. But these provide low-end functions such as learned on body. Hence, these have low safety guaranty.

Robotic system aims the provision of a grade of autonomy or a service to user that permanently or temporally lost part of their physical or mental ability. Many research institutes and universities are researching about assistant system for the elderly.

In Japan, Mechanical engineering research laboratory, Hitachi, developed an walking support system based on 486DX4 Processor[2]. This system focused in mechanical system; therefore it was weak in intelligent functions and user interface.

Pineau and Montemerio developed nursing home robot "Flo" and "Pearl"[3][4]. Each robot are equipped differential drive system and on-board PC, laser scanner, ultra-sound range sensor, microphone, touch sensitive graphical display, actuated head unit, and stereo camera system. These systems have the advantage of various functions and emotional design. But, these only focus for indoor environment.

In this paper, we propose architecture of the walking assistant robot for the elderly which is usable at indoor and outdoor environment.

This paper is organized as follows: In section 1 we present principles of the walking assistant robot system and in section 3 describe shared control strategy, walking intent recognition system and obstacle avoidance algorithm using laser scanner. In section 4, we present implemented robot system. In section 5, we present experimental results and conclude in section 6.

2. System Principles of the Walking Assistant Robot

2.1 Functions of the Walking Assistant Robot

Main functions of the robot are walking assistant and path guidance. It should guarantee safety and convenience. It requires as

- Seating and stand-up assistance
- Recognizing the user's walking intent
- Power assistance
- Localization and navigation guidance
- Obstacle detection and avoidance

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2.2 Mechanical Structure

We used Ackerman linkage such as those used in automobiles for the walking assistant robot. Two front wheels for steering and two rear wheels for driving are used. We assume that the robot always rotates around *ICR* (Instantaneous Center of Rotation)[5]. All wheels have same angular velocity. Fig. 1 shows concept of the Ackerman linkage. *ICR* has variable position and three singularity position.

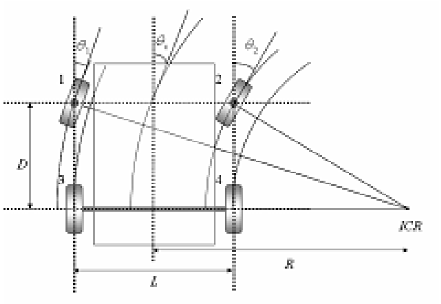

Fig. 1 Modeling of Ackerman linkage.

- Rotation by infinite point

When *ICR* is located in infinite position, the robot move straight forward. In this case, kinematics parameters of the are given by,

$$\theta_c = \theta_1 = \theta_2 = 0$$
$$\omega_3 = \omega_4 = \frac{v}{2\pi r} \quad (1)$$

where,

θ_c	heading of the robot
θ_1	steering angle of the far side front wheel form ICR of the robot
θ_2	steering angle of the near side front wheel form ICR of the robot
ω_3	angular velocity of far side wheel from ICR of the robot
ω_4	angular velocity of near side wheel from ICR of the robot

- Rotation by one of the rear wheel

When *ICR* is located on the one of rear wheel, kinematics parameters of the robot are given by

$$\theta_1 = \arctan\left(\frac{L}{D}\right) - \frac{\pi}{2}, \theta_2 = -\frac{\pi}{2}$$
$$\omega_3 = \frac{v}{\pi r}, \omega_4 = 0 \quad (2)$$

where,

L	width between each rear wheels
D	wheelbase. Width between center of front wheel and rear wheel
v	velocity of the robot
r	radius of the rear wheel

- Rotation by center of the robot

When *ICR* is located on the center of the robot, the robot only rotate and do no translate. Kinematics parameters of the robot are given by

$$\theta_1 = \arctan\left(\frac{L}{2D}\right) - \frac{\pi}{2}, \theta_2 = \arctan\left(-\frac{L}{2D}\right) - \frac{\pi}{2}$$
$$\omega_3 = -\omega_4 = \frac{\Omega}{2\pi r} \quad (3)$$

Where,

Ω	rotation velocity of the robot

Generally, kinematics parameters of the robot are given by

$$\theta_1 = \arctan\left(\frac{R + L/2}{D}\right) - \frac{\pi}{2}, \theta_2 = \arctan\left(\frac{R - L/2}{D}\right) - \frac{\pi}{2} \quad (4)$$
$$\omega_3 = \frac{(R + L/2)\Omega}{2\pi r}, \omega_4 = \frac{(R - L/2)\Omega}{2\pi r}$$

2.3 Electrical and software Structure

Figure 2 shows block diagram of the electrical structure of the robot. The main processor controls sensors, actuators and peripherals interface. Smart handle is used for user interface. It recognizes walking intent of user and sends data to main processor. Then, the main processor calculates kinematics and dynamics for driving actuators. The main processor sends rotation velocity value to motion controllers and controllers drive motors.

Laser scanner is used for obstacle detection. 2-D laser scanners are widely used within the mobile robotics community and have been applied to object following and obstacle avoidance[6][7]. GPS is designed to provide position, velocity, and time estimates to users at all times, in all weather conditions, anywhere on the Earth[8]. It used for navigation guidance in outdoor environment.

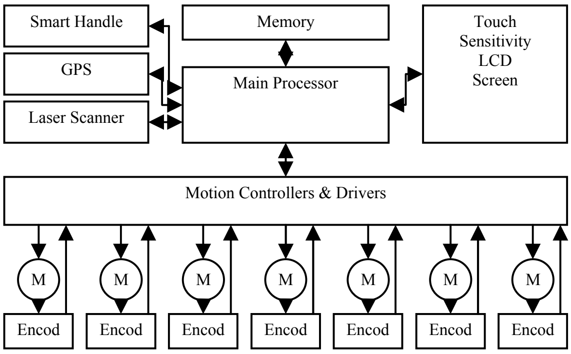

Fig. 2 Electrical structure of the walking assistant robot.

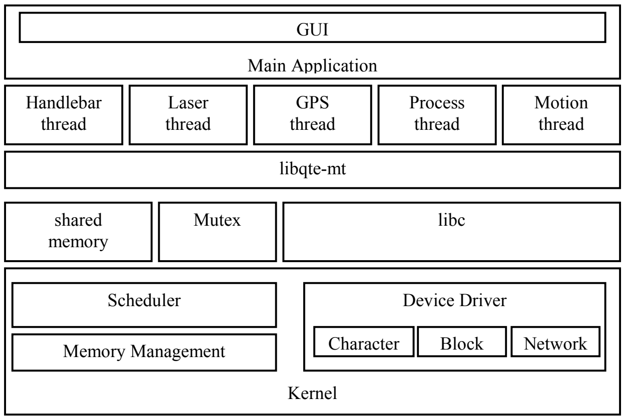

Fig. 3 Software structure of the walking assistant robot.

Software structure of the robot is based on multithreading system. The main system should control sensors and actuators concurrently. Therefore, we used multithreading. Multithreading is a process in which different parts of codes from a program, called threads, are executed simultaneously[9]. In a single thread environment, applications would typically multitask. That is, the operating system would quickly switch between several tasks that were running. Each task would be given a small piece of CPU time, or time slice. So while only one application had instructions being executed at any given point, the user was provided with the illusion that multiple processes were running at once. With multithreading, this process is taken one step further. Multithreaded application can divided up process into individual thread, and process each of these tasks at the same time.

When a program is broken up into threads, each unit is less complex than the whole. As a result, the program is generally simpler, more maintainable and scalable than if it was not threaded. Multithreaded programs can also take advantage of multiple processors. While all these benefits can be derived through the use of multiprocessing, multithreading is less expensive because it allows the CPU to be used more efficiently.

For communicate with thread, we used shared memory. Shared memory is one of the IPC(Inter-Process Communication) mechanism which enables different threads to communicate with each other as if these processes shared memory space. Hence, any thread sharing the memory region can read or write to it.

Figure 3 show whole layer of the robot software.

3. Shared Control Strategy

3.1 Modeling of Shared Control Framework for the Walking Assistant Robot

The modeling of shared control framework is divided into several discrete states [10]. The framework integrating the human supervisor into an otherwise autonomous control system has both continuous and discrete elements. The model of the complete system, which integrates the model of the human interactions, is comprised of four separate sub-systems. These sub-systems are the Human Discrete Event System (HDES), through which the human can interact; the Autonomous Discrete Event System (ADES), which generates commands such that the plant can achieve the goal; a continuous system, or plant, which execute the physical task; and an interface which facilities communication between the discrete and continuous sub-systems. Figure 4 shows an overview of the aforementioned sub-systems.

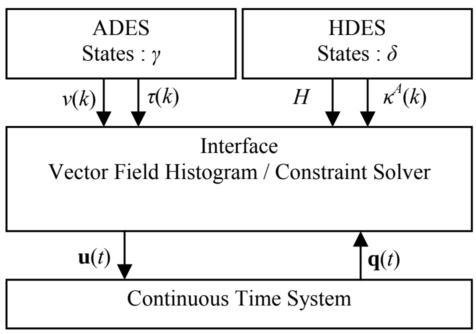

Fig. 4 Block diagram of a shared control system.

Wasson proposed shared control based on passive robotics and user intent[10]. But we proposed control strategy is based on active robotics instead of passive robotics. Active robotics can provide motive force, and can provide more powerful assistant. Figure 5 shows control system architecture for the robot.

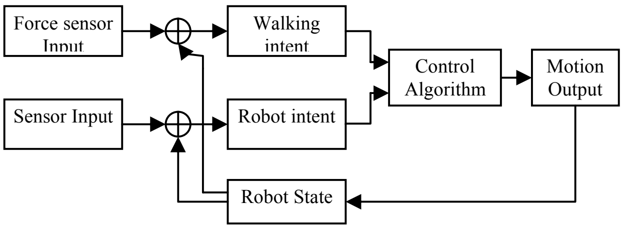

Fig. 5 Walking assistant robot shared control system architecture.

3.2 Walking Intent Recognition System

The walking assistant robot should react to user's moving intent. Particularly, we interested in user's walking intent. The robot acquires force signal from handles, then recognizes velocity and direction which user required. And robot decides velocity and direction of itself by result of walking intent recognition.

For evaluate user walking intent, we equipped force sensors in handles of the robot. If user push handles, it means that user require robot move straight forward. On the contrary, if user pull handles, it means that user require robot move straight backward. If applied force values between left and right side handles are different, it means user require turn around.

We use four FSR(Force Sensing Resistor)s in handles of the robot. When the FSR is unloaded, its resistance is very high. When a force is applied to the sensor, this resistance decreases.

Figure 6 shows structure of the smart handle. Handle consist of three parts. User takes center part of the handle which movable. Between each part, FSRs are installed. For stabilized output, Polyurethane dampeners are installed in both sides of FSRs.

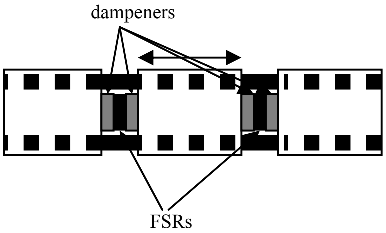

Fig. 6 structure of the smart handlebar.

3.3 Sensor Based Obstacle Avoidance System

For user safety, the robot sense environment using laser scanner. Laser scanner returned range reading every degree of a 180 degree sweep in front of the robot. Laser scanner based on the measurement of time-of-flight(TOF)[7]. As depicted in figure 7, a pulsed infrared laser beam is emitted and reflected from the object surface. The time between the trans-mission and the reception of the laser bean is used to measure the distance between the scanner and the object.

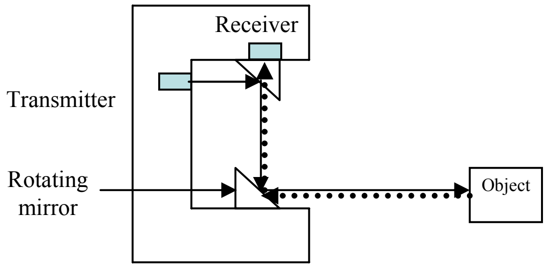

Fig. 7 operating principle of the laser scanner.

For navigation, a variation of the VFH+ algorithm [11] was used. It was attempted to use the VFH+ algorithm with standard ring of ultra-sound sensors alone but persistent specularities in sonar in the sonar returns resulted in undesirable robot behavior. When using the VFH+ with the laser scanner, it was not necessary to build a polar histogram as the range data from the laser scanner was sufficiently accurate to work on a single shot basis.

We propose modified vector field method for the avoidance robot. First, the robot checks obstacles in threshold area. We interest three vectors which start/end point vector and smallest vector. If laser scanner found obstacle, robot get width and shortest distance of obstacle. Second, robot evaluate that obstacle must be avoided. If an obstacle located in ROI(Region of Interest), robot avoid this obstacle. ROI is express with sector as

$$S = \frac{1}{2} r^2 \theta \tag{5}$$

where,

S Surface area of ROI

r radius of threshold circle (distance between the robot and obstacle

θ angle between start point and end point vector

θ depends on radius of threshold circle and width of the robot.

If obstacle located in ROI, robot finds free space and calculates width for get available moving space. Centers of each available moving space are being candidate of new path direction. New path direction is decided by applied user intent output.

$$\Theta_{new} = \begin{cases} \Theta_{original} + \min(\{|\Theta_{original} - \Phi_i|, 0 < i < n\}), \Phi_{\min} > \Theta_{original} \\ \Theta_{original} - \min(\{|\Theta_{original} - \Phi_i|, 0 < i < n\}), \Phi_{\min} < \Theta_{original} \end{cases} \quad (6)$$

where,

$\Theta_{original}$	original direction of path.
Θ_{new}	new direction of path.
Φ_i	ith candidate direction of new path
n	number of candidate direction of new path

Figure 8 shows geometric definition of the obstacle avoidance.

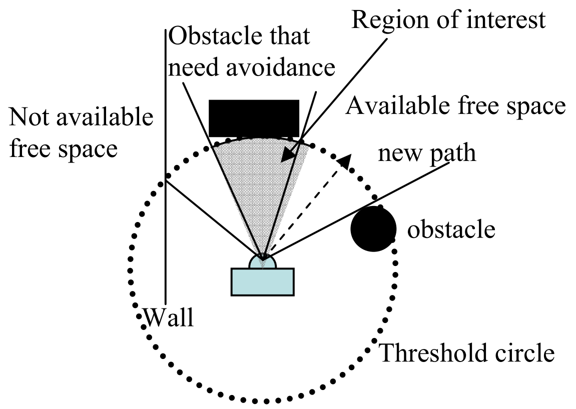

Fig. 8 Geometric definition.

4. Implementation

Mechanism of the walking assistant robot is similar to walker for the elderly. The overall width of the robot is 0.78m which can pass general doors.

We used five motors for driving, steering and lift up handle. For driving, we used two 100W DC motors. Two 20W DC motors are used for steering. And one 20W DC motor is used for lift up handle.

We used Intel PXA255 based single board computer for main process. The Intel PXA255 processor is a highly integrated, 32-bit RISC processor that combines the efficiency of Intel design with the ARM V5TE instruction set architecture[12]. This board supports Ethernet 10-baseT, 3-UART, touch sensitivity color TFT LCD display, PCMCIA/Compact Flash/MMC bus, IIS sound system, and USB 2.0 Host. It benefit from low power consumption and small size. Hence it serves purpose of the robot.

For process scheduling, we use embedded Linux version 2.4.19 for XScale. JFFS (Journaling Flash File System) is used for user file system. The robot equipped SICK laser scanner for detection obstacle. To control motors, we used a 3-axis motion controller DMC-03, and 2-axis motion controller DMC-02 manufactured by Hanool Robotics corporation. These controllers interface with main system using USB.

We use Qt toolkit for system control and user interface application programming development tool. The Qt toolkit is composed of graphic interface libraries and configuration software [13].

Figure 9 shows implemented walking assistant robot "Silbo" and Figure 10 show implemented smart handle and user interface.

Fig. 9 Implemented walking assistant robot.

Fig. 10 Smart handle and user interface.

5. Experimental Result

We have experimented path tracking using smart handle. This experiment verifies usefulness of smart handle as user operation interface. Figure 11 shows result of tracking path. Smart handle is as capable as joystick. In addition, smart handle provides more safety than joystick.

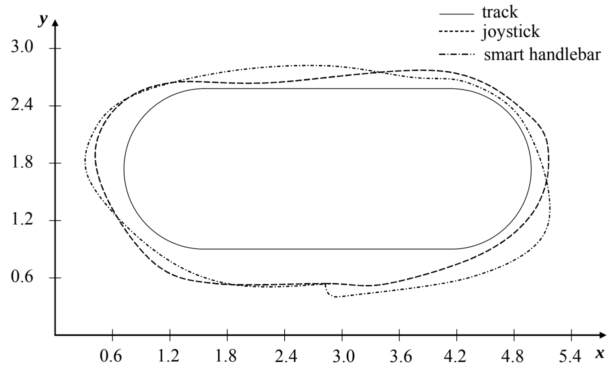

Fig. 11 Result of path tracking using joystick and smart handle.

Second experiment is verifies of safety of the robot. When obstacle in front of the robot, it avoids obstacles and move alternate path for moving to safe space. As a result, robot can guarantee safety from collision

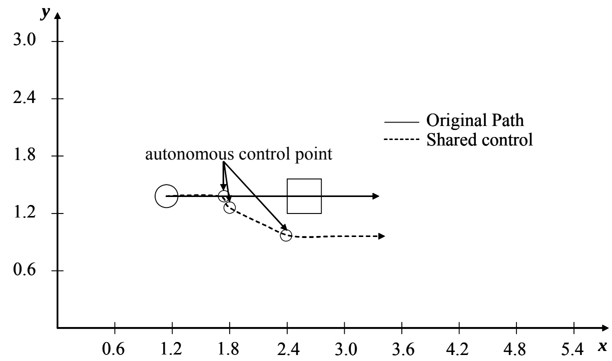

Fig. 12 Result of obstacle avoidance using shared control.

6. Conclusion

We developed walking assistant robot system and verified performance via experiments. The experimental results demonstrate the usefulness of the robot system.

The robot provides power assist and collision free operation by intelligent system architecture. In future work, we will enhance safety and intelligent for more convenient operation. We will research about intelligent walking intent algorithms and motion planning algorithm. We expect that this robot aids to growth of welfare system and robotic technology.

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