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Development of a Walking Assistive Service Robot for Rehabilitation of Elderly People

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1. Introduction

In order to realize a welfare community, where elderly and disabled people can comfortably live a normal life, it is essential to develop various devices and systems, using cutting-edge science and technology. In particular, there is an urgent need for the development of a human-friendly robotic system that is flexible and adaptable enough to meet the needs of our aging population, and the needs of disabled people living within the community. For walking exercises several items of auxiliary equipment are required to help the roles of the lower limbs. For traditional walking auxiliary equipment, these can be divided into the parallel bar (with the bottom part adjusted), which supports the walker at four points, crutches, which supports the walker at two points, and the cane which supports the walker at only one point. The parallel bar consists of two bars secured at an appropriate height in parallel: it is the most stable form of walking auxiliary equipment. The walker uses them to help him or her to stand straight, and balance the body while walking exercises are undertaken. With support at four points, parallel bars generally give stability, but since they are not externally secured, falls are possible. Its shortcomings include that the user cannot walk fast, and may have difficulty in walking up a slope. Crutches and canes are more commonly used. These buttress the weight of the user, thereby assisting weakened legs and lessening the weight carried, (which may also reduce pain) to enable more natural walking. However, these traditional rehabilitation devices depend upon use by and adjustment with the upper limbs and upper body, so that the degree of weight support is inconsistent and immeasurable. Furthermore, the energy consumption required in using these devices is considerable. Equipment such as the orthopedic scooter, the bath bike, etc., reduces the energy consumption and provides a larger degree of freedom of movement. However, they do not satisfy the basic needs in terms of adjustment of supporting strength.

BWS is an item of treatment equipment for rehabilitation exercises for patients with neurological damage. It was proposed in 1985 to assist the easy attainment of the natural walking pattern (L. Finch, 1991). In 1987, a cat that had its spine completely split was treated in a walking exercise program by using the weight support system repeatedly on a treadmill and it was then discovered that several aspects of walking in humans is similar to walking

in cats. However, before this method was used with human patients, a study was conducted with 10 ordinary people who had no mobility problems, walking on a treadmill with 70% or more of their weight supported. In this experiment there was no abnormal walking and up to 70% of BWS was found to be helpful. In rehabilitation BWS is now considered the most convenient method to overcome the difficulties in walking exercises (T. Pillar, 1991, A. Wernig, 1992, M. Visintin, 1994, S. Hesse, 1995). Patients with neurological problems have found exercises with BWS significantly better than exercising with no weight support. Walking in water would have a similar effect, but that, of course, would be very inconvenient. Barbeau(1987) designed and manufactured a broad range of rehabilitation devices. One involves the patient walk on the treadmill with an upper frame (that is adjusted by hand), supporting the weight of the patient. A robot assistant, AID-1 (T. I. Ide, 1986), uses compressed air to lift the patient's body and thereby lessen the weight. REHABOT, a device that lessens the patient's weight by the same method as AID-1, enables the patient to walk on a circular route. In the beginning, a parallel bar is used with this equipment, to allow patients who have orthopedic or central nervous system problems (which make the exercise more difficult) to use the equipment. The walking capability of healthy individuals is tested with 60% or more BWS. Norman (1995) redesigned the equipment, such that the treadmill and the BWS device used hydraulic power. When holding on the parallel bars to walk, the degree of support in any harness height could be adjusted, following the generated moment. In other systems, a spring is used to support the patient's weight with an almost consistent force. Many authors have studied the perpetuity of force that reduces weight bearing in lieu of the vertical movement of the harness. These efforts have been driven by the needs of orthopedic patients, where the force applied to a damaged skeleton must be controlled. Casalena (1995) proved that a mutual transformation is made between the location energy and the motion energy of gravity within each of the walking cycle. The percent of energy recovery under optimal walking speed reaches 65%. By using a spring, the external work of gravity on the muscle, which increases weight, is minimized.

In this paper, a new rehabilitation system is proposed, using a mobile robot. This system can provide rehabilitation exercises and a walking guidance system for patients suffering mobility problems or paralysis; it makes active exercise possible through the external force and independent strength of the patient. With this robot, the strengths and shortcomings of walking rehabilitation systems described above can be realized or resolved. The equipment is designed to be smaller and simpler than the existing systems, while securing the fullest degree of mobility for the user. Furthermore, this robotic system has the great advantage of making its use in remote treatment possible in the near future. Where a disabled or elderly person is currently treated at home or in a clinic with rehabilitation exercises, he or she may, in future, be able to do the exercise unassisted, and then transmit the result to the doctor, as necessary. Table.1 shows results of functional comparison of GRSR, developed in this study, and the other system.

2. Design architecture

2.1 Overview

The service robot consists of gait assistance and body weight support system. A user is attached from the wrist to the elbow, and moves with the machine. The mechanical design

of the gait rehabilitation service robot was established through extensive analysis of: motion range requirements of the elderly; anthropomorphic data; kinematic and kinetic data from published clinical gait analyses; ergonomic constraints; analysis of the control law; extended periods of testing with former prototypes.

2.2 Design criteria

Before design the system, critical requirements and constraints had to be explored. Preliminary design work therefore involved planning how to increase the users’ degree of freedom, as well as determining the necessary sensors for system control. The overall goal was to develop a system that would assist a user, weighing up to 75kg, in walking. First and foremost, the design has to be safe. Given the close proximity of man and machine, both the control and mechanical design must ensure the operator’s safety at all times, even during failure. The second requirement is functionality.

Functions	PAM-AID	iRobot	ReMeRob	WARD	GRSR
Grip for the elderly	O	X	O	O	O
LRF Use	O	O	O	X	O
BWS mechanism	X	X	X	O	O
Obstacle avoidance	X	O	O	X	O
User command system	O	X	X	X	O
Touch screen control	X	O	O	X	O

Table.1 Results of functional comparison of GRSR and other system

Related to this is a further requirement for comfort in use: the device should not interfere with the behavior of the user. There are three possible prototypes in designing the overall architecture of an integrated of gait assisting and body weight support system. Table.2 shows the developmental history of prototype for gait rehabilitation and body weight support of elderly. Prototype#1 and #2 were developed by Park and Han (2004). The proposed system in this study is based on the Prototype #3.

The gait rehabilitation system design must allow enough freedom of movement for the machine to follow the body of the user during walking. While the user walk, the natural motion of the upper body swings from to top to bottom and right to left. The right and left motion is mainly important for gait stability; the system incorporates top and bottom motion for weight supporting. The revolving joint of the robot user is placed on an orthogonal (right angled) axis orthogonal to the user’s sagittal plane (an imaginary plane that bisects the body from top to bottom). Essentially, the robot has 3 degrees of freedom; the gait assisting system has 2 degrees of freedom and body weight support system has 1 degree of freedom.

	GA System	BWS System
Proto-type #1
Proto-type #2
Proto-type #3

Table.2 Developmental history of prototype

2.3 Consideration of gait of elderly

Walking is a learned activity in which the moving body is supported successively by one leg and the other. Dynamic regulation of upright stance is essential to the safe and efficient performance of many activities of daily living. During the single limb support (approximately 40% of gait cycle for each limb) the body is in an inherent state of instability because the vertical projection of the center of mass passes along the medial border of the foot (D. A. Winter, 1991) and not within the base of support as suggested by Sudarsky (1990). For the swinging limb, the toe clears the ground by less than a centimeter as it travels at its highest forward velocity. The HAT(head, arm and trunk) segment represents about two thirds of the total body mass and has to be controlled by the hip muscle group to avoid tilting. The only period of stability is during double support phase and even during this period the two feet are not completely flat on the ground while the HAT segment travels at it is maximum velocity (V. T. Inman, 1981). Even if walking is performed almost unconsciously and largely automatically several sources of information help the subject to control walking. Dynamic walking balance is achieved by integrating sensory inputs from the visual, vestibular and proprioceptive systems (N. Teasdale, 1993, J. L. Poole, 1991, L. Wolfson, 1992) with adequate muscle strength, appropriate neuromuscular timing and free passive joint mobility (P. R. Trueblood, 1991). In normal aging, degeneration of one or more of these sensory systems occurs (R. W. Baloh, 1993, 2002) and may compromise balance during walking. Therefore, the elderly need some system that can help functions of these sensory systems and musculoskeletal systems for stable walking.

3. Control strategies

3.1 Basic approaches

In the walking-performance enhancing service robot, unlike traditional mobile robots, the human and the machine are integrated and in physical contact. This couples the dynamics of the hardware involved with control architecture. Several power assistance systems have been developed to amplify the strength of elderly people, but most successful research on gait assistance systems has been focused on rehabilitative devices for the physically disabled.

Figure.1 The controller of gait rehabilitation service robot

In these applications, the objective is usually to conduct a limited set of activities in a controlled environment, and many of the control schemes are used by machine. For integration of an appropriate control law, existing strategies are used. The controller of the gait rehabilitation service robot consists of an autonomous guided controller of the mobile robot for gait assistance system and a weight unloading controller of the body weight support system for gait rehabilitation as shown Fig.1.

First, in the case of the autonomous guided control, there are a lot of traditional control strategies for a mobile robot in terms of path generation and path tracking algorithms. The service robot has to achieve path generation and path tracking through the walking of the user, although it should incorporate obstacle avoidance in the environment. There could be a danger that if the user fell on or struck the service robot, it could turn with a short rotation radius or go backward. Therefore, for this service robot, a new control strategy has been designed using an integrating path tracking algorithm and a user-command detecting algorithm. Next, in the case of weight unloading control, the force to reduce weight bearing following the walking cycle has to be consistent at all times with the force measured by the strength sensor, which is fed back and operates the motor to lift.

3.2 Autonomous guide control

The use of the autonomous guided control of the gait rehabilitation service robot consists of four stages; building a local map, calculating a goal position, calculating a user's speed command, and path tracking.

In stage 1, environmental information acquired from a Laser Range Finder (LRF) is passed to the digital filtering. Because the LRF may pick up errors resulting from a beam scan, this data should be filtered before use. In stage 2, a user's speed command is calculated using a distance between the human and the robot. Sensing of this distance is achieved using a linear potentiometer. Stage 3 involves turning the LRF data into a goal position in Cartesian coordinates, using the Vector Field Histogram (VFH) algorithm and fuzzy logic. The goal position is then placed at a set distance away from the robot, and updated each computational cycle. In stage 4, Modified goal position and speed command obtained in stage 2 and 3 are inputs of the path-tracking algorithm. Outputs of the path-tracking algorithm are the angular velocity of each wheel motor of mobile robot.

Figure.2 Data flow diagram and control stage block of autonomous guide control

3.3 Map building

Building an environment map is crucial subject for the mobile robot navigation and a number of researches on map building have been investigated so far (J. J. Leonard, 1991, D. Hahnel, 2003). There are two categories of a map building algorithm, one is a grid map and the other is a topological map. These methods can be implemented by a laser sensor as well as an ultra-sonic sensor, an infra red sensor and a vision sensor. Especially, 2-D LRF is good device to obtain quickly the accurate shape of an object. A higher level of control is needed or there would be increased a difficulty in driving at high speeds.

3.4 User-command system

User-command system is man machine interface that transfer to the elderly' decision about walking to service robot, for example walking is continue or not and walking speed is

increased or decreased. The Upper limbs of the elderly are hard to be used by communicator because upper the limbs are used to reduce body weight load. Therefore, user-command system without using upper limbs of the elderly is necessary.

Fig.3 shows user-command system that was designed considering describing contents in front.

Figure.3 User-Command System of the GRSR

Using the mechanism such as Fig.3, it is kept the distance between service robot and human by speed control of service robot. But it does to prohibit that service robot travels backward for keeping the distance between service robot and human. Because the elderly can fall backward while use the service robot. The potentiometer is installed between the A plate and the B plate, then we measure degree of sliding between two plates.

3.5 VFH avoidance

We have used a method called the vector field histogram (VFH) (R. F. Vassallo, 2002). The VFH method employs a data-reduction technique. The data-reduction maps the active region C^* of the histogram grid C onto the polar histogram H , as follow: a window moves with the mobile robot, overlaying a square region of $w_s \times w_s$ cells in the histogram grid. The contents of each active cell in the histogram grid are now treated as an obstacle vector, the direction of which is determined by the direction β from the cell to the vehicle center point (VCP).

$$\beta_{i,j} = \tan^{-1} \frac{y_j - y_0}{x_i - x_0} \quad (1)$$

and the magnitude is given by

$$m_{i,j} = (C_{i,j}^*)^2 (a - bd_{i,j}) \quad (2)$$

Where,

a, b are positive constants,

$C_{i,j}^*$ is the certainty value of active cell (i, j) ,

$d_{i,j}$ is the distant between active cell (i, j) and the VCP,

$m_{i,j}$ is the magnitude of the obstacle vector at cell (i, j),
 x_0, y_0 are the present coordinates of the VCP,
 x_i, y_j are the coordinates of active cell (i, j), and
 $\beta_{i,j}$ is the direction from active cell (i, j) to the VCP.
 H has a arbitrary angular resolution α such that $n = 180 / \alpha$ is an integer. Each sector k corresponds to a discrete angle ρ quantized to multiples of α , such that $\rho = k\alpha$, where $k=0,1,2,\cdots,n-1$. Correspondence between $C_{i,j}^*$ and sector k is established through

$$k = INT(\beta_{i,j} / \alpha)$$

(3)

For each sector k, the polar obstacle density h_k is calculated by

$$h_k = \sum_{i,j} m_{i,j}$$

(4)

Each active cell is related to a certain sector by (1) and (3). A smoothing function is applied to H , which is defined by

$$h'_k = \frac{h_{k-l} + 2h_{k-l+1} + \cdots + 2h_{k+l-1} + h_{k+l}}{2l + 1}$$

(5)

h'_k is the smoothed polar obstacle density.

3.6 Fuzzy logic

The mobile robot that is to be developed in this study has to perform the functions to adjust the speed depending on the route generation, obstacle avoidance and walking speed of user. For this purpose, the direction of the target point, the location of the obstacle and the output of the force sensor are accepted as the input variables. The fuzzy rule determines the speed of autonomic mobile robot and turning radius from it. The fuzzy value of the input and output variables are designed to have the same values for each Table.3 and Table.4.

Variable	Fuzzy Sets
Vel. of Robot Body	SM BG
Steering angle	NE ZE PO

Table.3 Output Variables and Fuzzy Sets in Them

Variable	Fuzzy Sets
Obstacle distance	NAR MED FAR
Obstacle orientation	NBG NMD NSM ZER PSM PMD PBG
Obstacle Size	SML BIG
Goal orientation	NEG ZRO POS

Table.4 Input Variables and Fuzzy Sets in Them

The input and the output values of the fuzzy are expressed through the fuzzy group. Another word, the value of each has the membership function.

Rule Base

The rule that determines the speed of the robot is as follows.

→Move slowly if the obstacle is in front and near.

→If not, move fast.

The rule that determines the turning radius is as follows.

→Avoid if an obstacle is near but is not located in the rear.

→If an obstacle is in far distance, go toward the target point.

→If an obstacle is in the rear, go toward the target point.

→If an obstacle is in the mid-range and the size of the obstacle is small, go toward the target point.

The assumed rule used in this research is the max-min method of Mamdani.

$$z_0^i = \max(Z_1^i, Z_2^i, \dots, Z_N^i)$$

$$z_k^i = \min(A_k, B_k, \dots, C_k) \quad (k = 1, 2, \dots, N) \quad (6)$$

Here,

Z_0^i : Membership of first fuzzy group, z , of the output space

Z_k^i : Membership of i -th fuzzy group by the k -th rule

$A_k, B_k, \dots, C$: Membership of each of the fuzzy groups of A , B , and C of the input space used for the k -th rule

The defuzzification method used in this research is the CG point method.

$$Z^* = \frac{\sum_i \int \mu_i(z) \cdot z dz}{\sum_i \int \mu_i(z) \cdot dz} \quad (7)$$

Here,

$\mu_i(z)$: λ of i -th fuzzy group of the output space – cut ($\lambda = Z_0^i$)

A computer simulation for obstacle avoidance and route tracing as described above is made for the assessment of the capability of the fuzzy controller. The obstacle is experimented for the static obstacle and the dynamic obstacle. Fig.4(a) and Fig.4(b) displays the avoidance on fixed obstacle and the simulation result of route tracing.

In this research, the presumption is made for the obstacle with the conic formation with the semi-diameter of r . Fig.4(a) and Fig.4(b) display the result in each case of $r = 2$ and $r = 5$, respectively. Fig.4(c) demonstrates the avoidance on dynamic obstacle and the result of route tracing. To experiment the dynamic obstacle, two robots with the same controller is placed and set the environment to cross each other to reach to the target point. As shown on Fig.4(c), the robot in horizontal progress waits for the robot in vertical progress to pass.

Figure.4 Simulation of dynamic obstacle avoidance

3.7 Path tracking

In order to obtain simple kinematics modeling, Tong-Jin et al. investigated using the assumption that no slip conditions exist between the wheels of a mobile robot and the ground (T. Fong, 2001, T. Fukao, 2000). A mobile robot kinematics is controlled through steering which is derived from the velocity difference between the two driving wheels. Based on the kinematics model, a controller is designed to track to the reference path through user command when a mobile robot is diverted by an obstacle. Let $q_r = (x_r, y_r, \psi_r)^T$ the configuration of a reference mobile robot and its control inputs which are the translational speed $v_r(t)$ and the curvature time-derivative $l_r(t)$ (T. Hamel, D, 2001, 1999).

The tracking error vector between the reference mobile robot, q_r and the tracking mobile robot, q_t expressed in the vehicle frame by

$$q_e = T_e(q_r - q_t) \quad (8)$$

$$\text{Where, } T_e = \begin{bmatrix} \cos \psi_e & \sin \psi_e & 0 \\ -\sin \psi_e & \cos \psi_e & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

According to a mobile robot kinematic modeling and differentiating the equation (8), it yields

$$\begin{bmatrix} \dot{x}_e \\ \dot{y}_e \\ \dot{\psi}_e \\ \dot{l}_e \end{bmatrix} = \begin{bmatrix} v_r l_r^r y_e - v_r v_t + v_r \cos \psi_e \\ -v_r l_r^r x_e + v_r \sin \psi_e \\ v_r l_e \\ \dot{l}_r - u_t \end{bmatrix} \quad (9)$$

Where,

v_t : The relative velocity, $v_t = v_t / v_r$

l_r : The curvature of the reference trajectory, $l_r = \dot{\psi}_r / v_r$

l_r^r : The curvature of the real trajectory related to the reference trajectory,

$$l'_t = \dot{\theta}_t / v_t$$

l_e : The error of curvature, $l_e = l_r - l'_t$

In the nominal case (i.e., when the state variables are supposed to be exactly known), their proof of asymptotic stabilization of the proposed systems involves Lyapunov functions with negative semi-definite derivatives, and the convergence is proved by means of La Salle or Barbalat's theorem. Proving the stability of the origin $[x_e, y_e, \psi_e, l_e]$ can be easily done by considering the Lyapunov candidate function which is suggested as follows in this paper.

$$V(x_e, y_e, \psi_e, l_e) = x_e^2 + y_e^2 + l_e^2 + K_1(1 - \cos \psi_e) + (K_2 l_e + K_3 \sin(v_r) \cdot \psi_e)^2 \quad (10)$$

The time derivative of the equation (10) is as following.

$$\dot{V}(x_e, y_e, \psi_e, l_e) = -|v_r|(2x_e^2 + K_1(K_2 l_e + K_3 \cdot \sin(v_r) \cdot \psi_e)^2 + 2l_e^2 + K_1 \cdot \psi_e \cdot \sin \psi_e) \quad (11)$$

K_1 , K_2 and K_3 are control gains for handling the convergences of parameters. Equation (11) is negative definite for all ψ_e in $-\pi < \psi_e < \pi$. Using the Lyapunov theorem, the stationary point, $(x_e, y_e, \psi_e, l_e) = 0$ is the only stable equilibrium point inside the subset $\{\psi_e, \psi_e \in -\pi < \psi_e < \pi\}$ although $\dot{V}_e(x_e, x_e, \psi_e, l_e)$ is zero inside the set $\{x_e = 0, l_e = 0, y_e = -\eta, \sin(v_r) \cdot \psi_e, \psi_e \in -\pi < \psi_e \leq \pi\}$.

It can be asserted in a large positively invariant domain. Equation (11) has three control gains, K_1 , K_2 and K_3 that should be tuned under stability constraints $K_1 > 0$, $K_2 > 0$ and $0 < K_3 < 1$. In other words, these parameters are turning parameters for system's convergence. The good tuning - rule consists in specifying a well-damped behavior of the error system literalized around a situation where a reference mobile robot moves at a constant speed along a straight path.

A dynamic state feedback, stabilizing the dynamic error of equation (11) around zero, is as following:

$$v_t = -\frac{1}{2} l'_e (K_2 \cdot l_e + K_3 \cdot \sin(v_r) \cdot \psi_e) + K_3 \cdot \sin(v_r) \cdot x_e + \cos \psi_e \quad (12)$$

$$u_t = \dot{l}_r + |v_r|(K_1(K_2 \cdot l_e + K_3 \cdot \sin(v_r) \cdot \psi_e) + 2l_e + K_3 \cdot \sin(v_r) \cdot \sin \psi_e) \quad (13)$$

The control inputs v_t , u_t are derived by satisfying robust condition, the Lyapunov stability. x_e , y_e are tracking minus l_e and ψ_e is tracking the orientation of a reference mobile robot applying a robust term, sinusoidal term. The control inputs equations (12) and (13) is applied to the parking problem, one of the tracking problems (M. L. Corradini, 2001). The inputs in a reference mobile robot are as following:

$$u_1 = \alpha \sin(wt) \quad (14)$$

$$u_2 = \beta \cos(wt) \quad (15)$$

The periods of x_1 and x_2 are $2\pi / w$ [sec] and the magnitude of x_3 is $\pi\alpha\beta / w^2$ using the inputs, equations (12) and (13). Then the kinematic equations of a reference mobile robot are as following:

$$\dot{x}_M = \cos\psi_M \cdot u_1 \quad (16)$$

$$\dot{y}_M = \tan\psi_M \cdot \cos\psi_M \cdot u_1 \quad (17)$$

$$\dot{\psi}_M = u_2 \quad (18)$$

If the desired coordinates x_{Md} , ψ_{Md} are selected by user, the magnitudes of equations (14) and (15) are as following:

$$\alpha = \frac{x_{Md} \cdot w}{1 - \cos wt} \quad (19)$$

$$\beta = \frac{\psi_{Md} \cdot w}{\sin wt} \quad (20)$$

3.8 Weight unloading control

In the body weight support system, the perpetuity that lessens the weight bearing than the vertical movement of the harness is more important. The aforementioned importance of force has the theoretical foundation in the event of the orthopedic patients who must control the strength applied to the damaged skeleton. Cavagna proved that the mutual transformation is made in between gravity location energy and exercise energy within each walking cycle (P. R. Cavanagh, 1995). Under the optimal walking speed, the percent of the energy recovery reaches to 65%. In this method, the external work of muscle on accelerating gravity of weight center is minimized. If the force (F_0) to lessen the applied weight bearing is consistent while walking, this mechanism is preserved. In such a case, there is no need of requiring this strength. If F_0 is expressed in a part of weight, S , the force for the earth gravity direction, R_s , that applies to a patient is

$$R_s = Mg(1 - S) \quad (21)$$

This makes the patient as if he feels like walking with less gravity. However, this is not the case if F_0 is inconsistent. The external undertaking would not be zero and the mechanism to save energy will be significantly in mess. Therefore, the force to lessen the weight bearing has to be consistent at all times. The motor is operated by feeding back the force measured by the strength sensor that the lifting is made with consistent force at all times. Furthermore, in the event that a patient lost the walking capability, it is recognized to prevent the falling by the loss of strength in the lower limbs to help the safety of the patient.

The user who is equipped with the body weight support system may feel as if walking in water or zero gravity condition while walking.

4. Experimental results

The gait rehabilitation service robot that uses the mobile robot and newly designed BWS system are manufactured in respective module to formulate the integrated walking rehabilitation system. (Fig.5)

In this section, two experiments for verifying the capability of the gait rehabilitation service robot are achieved about walking guide system and body weight support system.

Figure.5 Captured pictures of a robot actuation movie file

This experiment has numerous limitations to place on the patients as subjects that the ordinary persons are selected as the subject of experiment. An adult male of 30 years of age, 172cm of height, and 68kg of weight and an adult male of 27 years of age, 165cm of height, and 54kg of weight are selected as the subjects.

4.1 Walking guide system

The control input is the angular velocity of both side wheels. In a real system, the angular velocity is transformed to -5~5 voltage, and is inputted to the motor driver. The commands of velocity may increase the errors to the final arrival point; however, this error may be ignored because of its small value within large-scale navigation. With consideration for the limits of motor angular velocity, the maximum velocity is set to 5.23 [rad/sec].

Fig.6 shows that a walking guide system is tracking the reference path identical to the initial condition. In this experiment, control of the wheel was satisfactorily achieved under experimental conditions, but there were some errors. As a road surface is not perfectly flat, the error caused by the road surface can be regarded as unmodeled error between the road surface and a mobile robot's wheels. The error was measured as a distance between the final point after 40 sec and vertical distance from the service robot's center in navigation. A number of trials showed the average of the errors to be 0.52 m. The average error was 0.66 m in experiment. Considering unmodeled error, the value of error may be regarded as 0.14 m in the experiment. There are a number of causes for this error. The most significant cause is the friction and slip between the surface of the ground and a mobile robot wheels. A mobile robot with a 2WD type has a nonholonomic characteristic but this experiment shows that the controller is fairly good for path tracking.

(a) Result of path navigation in an experiment for the path tracking algorithm

(b) Result of tracking wheel velocities in an experiment for the path tracking algorithm

Figure.6 Path tracking experiment

4.2 Body weight support system

For the details of the experiment, a comparison is made by the experiment on whether the force lifted from the body weight support system is consistently maintained and the EMG measurement following each body weight support system level. Table.5 is the experimental condition on this test.

	BWS Level	Velocity
Experiment condition	- Full weight - 20 % BWS - 40 % BWS	0.2 m/s

Table.5 Experiment on the EMG Signal

Figure.7 Captured pictures of a body weight support system actuation movie file

Figure.8 Picture of surface electrodes placed on lower extremity muscles

As shown in Fig.8, Surface electrodes were placed over the following muscles on the subject’s dominant side: the quadriceps femoris(QF), medial hamstrings(MH), gastrocnemius(GA), and tibialis anterior(TA). Prior to the application of the surface electrodes, the subject’s skin was shaved and cleaned with alcohol. Two electrodes were

placed over each muscle with an interelectrode distance of approximately 1cm. During the testing session the subjects walked at 0.2m/s with 0% level during each of the following harness supported ambulation situations: full body weight (FWB), 20% body weight supported (BWS), and 40% body weight supported (BWS). Five seconds of EMG data (1024Hz) were recorded for each condition. The raw EMG was collected using Myosoft software (Noraxon USA®, Scottsdale, AZ®). An analog signal was recorded using the Myosoft software. (Fig.9)

Figure.9 Raw data of EMG signals obtained on full body weight condition

Table.6 and table.7 list the average muscle activity for each muscle group expressed as a percentage of the FWB amplitude. Average EMG activity did not change significantly for any of the muscle groups when FWB was compared to 20% BWS ambulation. The average amplitude for quadriceps decreased to 91.6% of the FWB value, while average hamstring, gastrocnemius and tibialis anterior activity decreased to 96.9, 90 and 99.1% of the FWB value, respectively.

The average EMG activity decreased significantly from FWB to 40% BWS ambulation in the quadriceps muscles, but did not change significantly for the hamstring, gatrocneimius and tibialis anterior muscles. The average amplitude for quadriceps decreased to 72.8% of the FWB value, while the hamstring, gastrocnemius and tibialis anterior activity decreased to 85.9, 91.9 and 98.2% of the FWB value, respectively. The results suggest that muscle activation can be preserved while possibly decreasing load at the joint of lower extremity.

	Q*	H*	G*	T*
FWB	100	100	100	100
20%BWS	91.6	96.9	90	99.1
40%BWS	72.8	95	91.9	98.2

(*Q: Quadriceps, H: Hamstrings, G: Gastrocnemius, T: Tibialis anterior)

Table.6 Average muscle activity (EMG) expressed as a percentage of the FWB amplitude

	Q*	H*	G*	T*
Without robot	57.5	101	67.8	89.2
With ReMeRob	56.1	45.6	72.2	91.4
With RSR (20%BWS)	43	94.9	65	84.6

Table.7 %MVIC of muscle activity (EMG)

5. Conclusions

The gait rehabilitation service robot is developed for the elderly using mobile robot platform in this study. The action scope and the service mechanism of the robot are developed for consideration and analysis of the elderly gait. Also, the robot action is determined by environment information and the distance the elderly and robot. The environment information and distance the elderly and robot are acquired by measuring laser range finder and the linear potentiometer. Obstacle recognition in order to guide was presented and experimentally evaluated. The results of the experiments show that the mobile robot is tracking the reference path using a laser range finder. A robust path tracking algorithm for the path navigation of a 2WD mobile robot is proposed. Path tracking is performed by the robust controller based on a kinematic modeling. The reference path generation algorithm consisted of VFH avoidance and fuzzy logic for guide could be confirmed by the experiments. In gait assistance system’s view, the conclusions of this study are as follows: First, the performance of a local map building was enhanced using the Kalman filtering based on the dynamic modeling of a laser range finder. And VFH avoidance and fuzzy logic were suggested in order to apply the path tracking algorithm. Second, Robustness with a modifiable convergence was constructed by using a Liapunov function with control gains. The path algorithm was verified the availability by applying and implementing the path algorithm to the service robot. Third, User-command system was suggested by man machine interface that transfer to the elderly’ decision about walking to service In body weight support system’s view, the conclusions of this study are as follows: First, the gait velocity was selected as an ergonomic design parameter of the service robot from investigating the elderly gait data. Second, the weight unloading force measured by the load cell was controlled in body weight support system and A 4-bar linkage was applied to mechanism of the body weight support system; that is, part of mechanism contacted user’s upper arm keeps horizontality continuously. GRSSR is designed for elderly to communicate with remote site. The elderly can be treated by internet using web-cam image communication in remote site. Remote therapy or Doctor can be undertaken via tele-monitoring, thereby reducing length of hospital stay and avoiding unnecessary admission. Further, this system can be used as emergency calling and means of useful information acquisition for elderly. Fig.10 shows the wireless internet communication software and an image communication based on a web-cam through the internet. These are examined as ergonomic design parameters for the service robot.

(a) Realization of Basic Internet On-line System on GRSR

(b) Concept of Web Communication

Figure 10. Web Communication

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The aim of this book is to provide new ideas, original results and practical experiences regarding service robotics. This book provides only a small example of this research activity, but it covers a great deal of what has been done in the field recently. Furthermore, it works as a valuable resource for researchers interested in this field.

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