New and Emerging Technologies in Assistive Robotics

Workshop at IEEE/RSJ IROS 2011, Sep. 26 2011

Introduction

The number of people with disabilities and the complexity of needs that they and their families experience continue to increase, despite the improvements in technology and health care. This increase is also directly related to the rapid ageing of the world population. The goal of Assistive Technology is to develop advanced technical aids for promoting independent living and improving quality of life of persons who have chronic or degenerative impairment in motor, sensory, communication and/or cognitive abilities. The aim of this workshop is to describe the innovative and interesting research activities in robotics with applications to people affected by disability and by older people with degenerative disorders due to the natural course of aging. Topics include mobility aids for locomotion or navigation, automated manipulation systems, personal robotics, multi-modal human-machine interfaces for assistive robotics, interaction control of assistive robots, socially assistive robots, activity monitoring systems, telerobotics and telemedicine, and elder-care assistive robots.

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Workshop program

Date: Sep. 26 2011

Time: 9:00 – 12:10

Introduction (9:00 – 9:05 min)

Dr. Kazuyoshi Wada

Invited Talk Session I: (9:05 – 9:45)

Dr. Takanori Shibata (AIST) (9:05 - 9:25, 15 min + 5 min Q&A)

"Robot Therapy for Victims of Disaster by Earthquakes in Japan and for Elderly with Cognitive Disorder by using Seal Robot, a Biofeedback Medical Device"

Dr. C. Balagure (Universidad Carlos III de Madrid) (9:25 – 9:45, 15min + 5 min Q&A)

"SULTAN: Simultaneous User Learning and Task Execution, and its Application in Assistive Robotics"

Teaser Session: (9:45 – 10:15)

[Presentation 1] (4 min)

D. Trabelsi, S. Mohammed, F. Chamroukhi, L. Oukhellou, Y. Amirat, "ACTIVITY RECOGNITION USING HIDDEN MARKOV MODEL REGRESSION"

[Presentation 2] (4 min)

P. Viswanathan A, J. J. Little A, A. K. Mackworth A, A. Mihailidis B, "Adaptive Navigation Assistance for Visually-Impaired Wheelchair Users"

[Presentation 3] (4 min)

K. E. Green, B, I. D. Walker, J. Brooks, T. Threatt, J. Merino, "AN ASSITIVE ROBOTIC TABLE (ART) PROMOTING INDEPENDENT LIVING"

[Presentation 4] (4 min)

N. Pedrocchi, M. Malosio, F. Vicentini, L. Molinari Tosatti, M. Caimmi, F. Molteni, "Evaluation of the Impact of Force Control and Motion Laws in rehabilitation"

[Presentation 5] (4 min)

D. O. Popa, I. Ranatunga, D. Hanson, F. Makedon, "NEW ROBOTIC TREATMENT SYSTEMS FOR CHILDHOOD CEREBRAL PALSY and AUTISM"

[Presentation 6] (4 min)

W.-K. Song, J. Kim, W.-J. Song, Y. Kim, B.-S. Lee, "NOVEL SELF-FEEDING ROBOT FOR KOREAN FOOD"

[Presentation 7] (4 min)

S. Šabanović , T. Shibata, L. Huber, “AROUND THE WORLD WITH PARO: CHALLENGES IN DESIGNING AND USING ASSISTIVE ROBOTS ACROSS CULTURES”

Coffee break: (10:15 – 10:30)

Poster Session: (10:30 – 11:00)
[7 poster presentations]

Invited Talk Session II: (11:00 – 11:40)
Dr. Bram Vanderborght (Vrije Universiteit Brussel) (11:00 – 11:20, 15 min + 5 min Q&A)
“KNEXO: a Knee Exoskeleton to test design and control concepts for gait rehabilitation”
Dr. Yasuhisa Hirata (Tohoku Univ.) (11:20 – 11:40, 15 min + 5 min Q&A)
“Human Assistive Robot Systems Controlled by Servo Brakes”

Panel/open discussion and conclusion (11:40 – 12:10)
Moderator: Dr. Machiel Van der Loos
[Time (30 min)]
Panelists: Workshop Speakers

Invited talk session I

Robot Therapy for Victims of Disaster by Earthquakes in Japan and for Elderly with Cognitive Disorder by using Seal Robot, a Biofeedback Medical Device

Takanori Shibata
Senior Research Scientist, AIST

Abstract:

Robot therapy, which uses robots as substitution for animals in “animal therapy,” is a new application of the robots in welfare and medical fields. The seal robot named PARO has been developed especially for the robot therapy since 1993. PARO was commercialize in Japan in 2005 and in Europe and the US in 2009, and has been used at hospitals and facilities in about 30 countries. Recent researches revealed that robot therapy has the same effects on interacting people as like animal therapy. In 2009, PARO was certified as a “biofeedback medical device” by the Food and Drugs Administration (FDA) in the US. PARO can be applied to various kinds of therapy as like real animals, but this presentation focuses on applications to elderly with dementia because explicit differences before and after interacting with PARO can be easily observed. Some typical cases and interesting special cases will be introduced. In addition, PARO has been healing victims of disaster by earthquakes in Japan. PARO visited about 20 evacuation shelters, and has been used at about 50 elderly institutions, hospitals, and schools in the disaster area.

SULTAN: SIMULTANEOUS USER LEARNING AND TASK EXECUTION, AND ITS APPLICATION IN ASSISTIVE ROBOTICS

C. Balaguer [A], A. Jardón [A], C.A. Monje [A], F. Bonsignorio [A,B], M.F. Stoelen [A], S. Martínez [A], J.G. Victores [A]
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INTRODUCTION

The main objective of this work is to present a mechanism called Simultaneous User Learning and TAsk executioN (SULTAN). In SULTAN the model of the user maintained by the system's learning module and the system's representation of the physical interaction tasks are concurrently refined (in analogy with SLAM), keeping explicit account of the user's own learning. The process is as such seen as a mutual adaptation learning process. It aims to augment the users' ability to perform daily tasks by a new concept of intelligent service robotic system capable of physical and cognitive collaboration. One of the potential applications is in assistive robotics (see Figure 1), and the main focus is on creating a human+robot binomial in which: a) the robotic system will use, not ignore, the human perception and cognitive abilities in order to safely achieve the tasks that would be too complex to perform in a purely autonomous way, and b) the human will not be a mere teleoperator of the robot but will take advantage of the acquired knowledge of the robotic system to augment her/his action and perception capabilities.

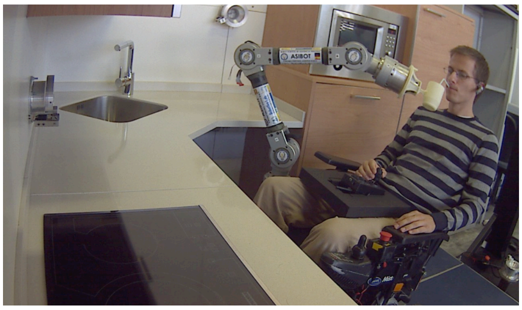

Figure 1. ASIBOT robot [1] working with a user in a real kitchen environment.

THE SULTAN CONCEPT

The SULTAN learning process is based on hierarchical Bayesian networks [2,3,4]. Building on the Bayesian Approach to Cognitive System (BACS) EU project, see for example [5], a probability is assigned to all possible interpretations of the available human+robot sensory and motor information, on the basis of sensory or motor noise and priors designating the most likely interpretation. The motor output (following a Robot Parametric Path, RPP, a parameterized and probabilistical representation of a given task) corresponds to the interpretation that has the most probable, or the most desirable, outcome. The SULTAN concept sets the problem in a user-task-object domain to solve the challenge of how to robustly perform a set of tasks for different users in different environments by the same robot, see Figure 2. For example, a situation where a user (Martin) commands the robotic system to perform a specific task (pick) with a specific object (can), using the user's perception abilities (eye tracking) and his satisfaction index (quality of the path). The storyline of the SULTAN system begins with the KDB (Knowledge Data Base) empty, except for some information of the robot and the user. During the first stage of SULTAN the user moves the robot in a fully teleoperated mode, using his/her knowledge and his/her perception, and interacting with the real world. The KDB is learning by the continuous updating of the RPPs parameters. While the user repeats the tasks, the robot's control changes from fully teleoperated to semi-autonomous mode with less and less intervention of the user. Some of the

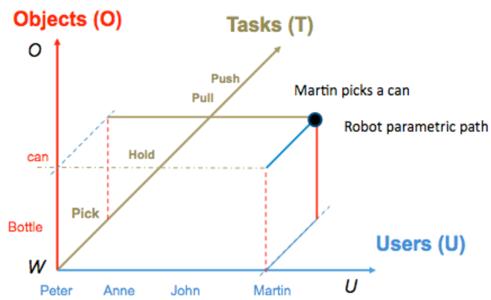

Figure 2. The SULTAN dimensional relationships.

parts of the RPP will be executed in a fully autonomous way. When the number of tasks is sufficient and the RPP parameters adjustment is finished, the robot can move fully autonomously using its own perception and control system and the updated KDB. The users only supervise the system. This process will be repeated for different users (Peter-pick-can), different tasks (Martin-hold-can) and different objects (Martin-pick-bottle), this way creating the full KDB. At this point the storyline is finished and the robot will work with a certain degree of autonomy.

FIRST IMPLEMENTATION

The scope of the software architecture required for realizing SULTAN ranges from high (user interaction-level) to low (hardware interaction-level) aspects of design. The multimodal interaction will be interpreted at a semantic level and used to plan a desired task. This process uses information that has been collected from the environment and the knowledge that exists about a given user (in the before-mentioned KDB). A learning agent generates this knowledge by observing the user inputs, task progress and contextual information, simultaneously learning with the user. The generated task is performed and monitored using information from the external sensors and the robot's own propioceptive sensors. Benchmarks for human performance on typical DLAs are being established. See for example the trajectories for two users (without disability) performing simplified DLAs in a virtual environment in Figure 3. These benchmarks can be used to put the performance of the human+robot binomial in perspective and to aid in the design of shared control and intent recognition capabilities. A pilot study was also performed, in the same environment, to investigate the adaptation of the interaction for a robot capable of providing physical assistance to disabled users. The subjects were three non-disabled users. A simple shared control scheme was implemented, which limits the velocity of the end-effector commanded by the user in the direction where obstacles are detected, proportionally to the distance measured. All sessions, except the control session, had Gaussian noise added which was low-pass filtered at 2 Hz and which increased in magnitude proportionally with the magnitude of the velocity commanded by the user. As it can be seen from Figure 4, the noise added did seem to have a negative effect of the performance of the subjects. The average Mean Time (MT) over subjects was increased from 6.15 to 10.04 seconds. This was seen even clearer in the predictive information metric, $I(A_t;A_{t+1})$, the mutual information across the shared control output (A) at subsequent moments in time [6]. This indicates this metric's sensitivity to the reduction in the "predictability" of the trajectories with the noise added. The shared control had a positive effect, reducing MT to 7.43 seconds. This improvement was seen also in the other two metrics, especially in the mutual information across the noise added, Z, and the shared control output, i.e. $I(Z_t;A_t)$.

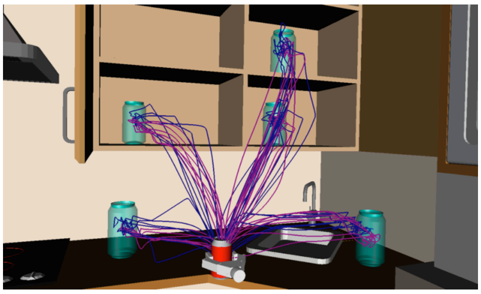

Figure 3. Trajectories for two users placing a can in a virtual kitchen.

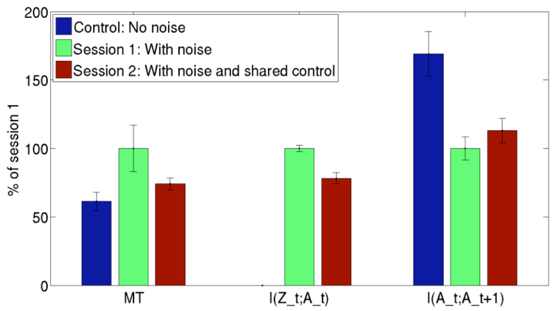

Figure 4. Preliminary results for the effect of noise and a simple shared control system.

CONCLUSIONS AND FUTURE WORK

In this paper we have presented the novel SULTAN concept as a mechanism that allows the augmentation of personal capabilities to perform daily tasks through the creation of a human+robot binomial in which physical and cognitive collaboration is achieved as a whole. The novelty of this approach is discussed and in order to demonstrate the applicability of the SULTAN idea, the first experimental results from its implementation have been given. Further research will focus on the implementation of the complete SULTAN architecture, closing the loops between all its levels and integrating it in different robotic systems, including assistive robots.

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Teaser session

ACTIVITY RECOGNITION USING HIDDEN MARKOV MODEL REGRESSION

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INTRODUCTION

The increasing number of elderly in the world poses specific health challenges for healthcare services and their adaptation to the needs of this aging population or to dependent people in general. The purpose is therefore to facilitate the daily lives of this kind of people, increase their autonomy and improve their safety. Due to the emergence of accurate, efficient and novel adapted technologies, assistive robotics is becoming a privileged solution to provide assistive services to humans, such as health monitoring, well being, security, etc. Within the general human activity monitoring context, one can notice the importance of the physical human activity recognition that has been extensively studied over the last decades. Most of the human activities classification techniques in free-living environment are based on the use of inertial sensors and in particular the accelerometer-based systems [1][2]. In this study we propose an approach that combines a statistical model and the use of the acceleration data acquired during a sequence of different static and dynamic human activities. As the sequence of acceleration data can be seen as a multidimensional time series where each dimension is an acceleration, the activity recognition problem is therefore formulated as a problem of multidimensional time series segmentation where each segment is associated with an activity. Formally, the proposed approach is based on hidden Markov models in a regression context. Each activity is represented by a regression model and the switching from one activity to another is governed by a hidden Markov chain. The parameters of the regression model are learned in an unsupervised way from the raw acceleration data acquired during human activities. The most likely sequence of activities is then estimated using the Viterbi algorithm [3]. The proposed technique is evaluated on real-world acceleration data issued from an assistive robotics oriented application. The comparison with well-known supervised classification methods shows that the proposed method is competitive even if it performs in an unsupervised framework.

MATERIALS AND METHODS

In this study, human activities are classified using three sensors placed at the chest, the right thigh and the left ankle respectively as shown in Figure 1. Raw acceleration data are collected using three MTx 3-DOF inertial trackers developed by Xsens Technologies [4]. Each MTx unit consists of tri-axial accelerometer to measure the acceleration in the 3-D space. The sensor's placement is chosen to represent the human body motion while guaranteeing less constraint and better comfort to the wearer. The activities were performed at the LISSI Lab/University of Paris-Est Créteil (UPEC) by six different healthy subjects of different ages. Twelve activities were considered: Climbing down stairs, Standing, Sitting down, Sitting, From sitting to sitting on the ground, Sitting on the ground, Lying down, Lying, From lying to sitting on the ground, Standing up, Walking, Climbing up stairs. The acquired acceleration data, as they present measurements from different activities over time, can be seen as multidimensional time series presenting various changes in regime; each regime describing an activity. The problem of classification therefore becomes the one of regime detection or segmentation. The piecewise regression [5] is one of the most adapted modeling approaches for time series. However, the parameter estimation in such method requires the use of dynamic programming algorithm [6], which may be computationally expensive. Another way for time series modeling is to use a hidden Markov model (HMM) [7], which is a well-known approach that assumes that the data are arranged in sequences and are therefore time-ordered. We consider in this paper an approach based on hidden Markov model regression [8] which can be seen as an extension of the standard HMM to regression analysis, each regime is described by a regression model, while preserving the Markov process modeling for the sequence of unknown (hidden) activities. In such a context, the main idea is to partition the data into different segments (regimes), each segment being considered afterward as an activity. The model is described by a set of regression parameters for the different regimes and the Markov chain parameters which are the initial probability distribution of the classes and the transition probabilities from one activity to another over time. The model parameters are estimated by maximizing the likelihood of the acceleration data by a dedicated iterative algorithm known as the expectation-maximization (EM) algorithm [9]. Once the model parameters are estimated, the optimal sequence of activities is then determined by using the Viterbi decoding algorithm [3].

Results and Discussion

The proposed technique was assessed by comparing it to some alternative supervised classifiers such as Multilayer Perceptron, Naïve Bayes, kNN, SVM and Random Forest for which the class labels are available. The used data present the real acceleration data that cover 12 static and dynamic activities. The proposed approach provides 91.47% as a mean correct classification rate. Figure 1 right shows an example of raw acceleration data and the probability of each activity over time according to the proposed model.

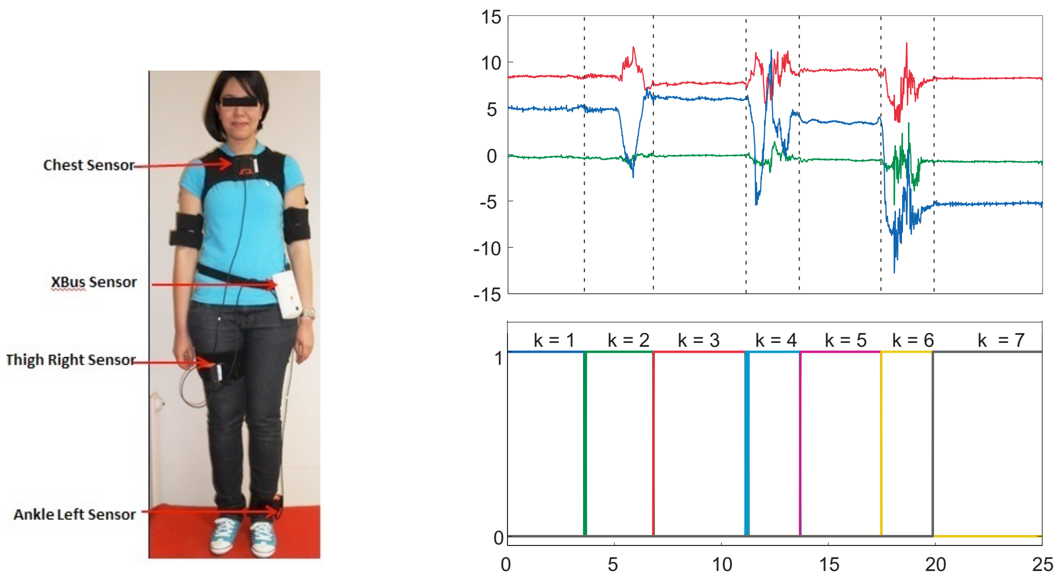

Figure 1 MTx sensors placement and results for segmentation of the sequence (Standing - Sitting down - Sitting - From sitting to sitting on the ground - Sitting on the ground - Lying down - Lying) for the seven classes k = (1, … , 7)

It can be observed that the probability of each activity is very close to one if that activity is active and to zero otherwise, showing hence an efficient segmentation of the data according to the true scenario of activities. The used supervised classifiers provide correct classification rates between 80.9% and 95.9%. The proposed approach seems promising as it provides very encouraging results in an unsupervised context compared to standard supervised classification techniques (using class labels). Indeed, even if the proposed methodology is not supplied with observation labels, the results obtained on real dataset are challenging and the segmentation technique that was proposed can be used as an efficient tool for automatic human activity recognition. This performance can be attributed to the fact that the proposed approach takes into account the sequential appearance and temporal evolution of the data to easily detect activities and especially from the measured accelerations. It could therefore serve as a decision support tool in the context where activities cannot be necessarily labeled (unsupervised framework).

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Adaptive Navigation Assistance for Visually-Impaired Wheelchair Users

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INTRODUCTION

It is estimated that approximately 10% of people who are legally blind require wheelchairs [1]. Wheelchair users with visual impairments face difficulties in avoiding obstacles as well as identifying visual cues in the environment, thus making independent navigation challenging, and in some cases, impossible. The authors in [1] suggest that intelligent wheelchairs capable of collision avoidance and path planning would greatly benefit wheelchair users with visual impairment. Although several intelligent wheelchairs have been developed recently [2-4], these wheelchairs navigate autonomously, thus taking control away from the user. On the other hand, wheelchairs that only provide collision avoidance support [5] are not appropriate for drivers who are unable to determine their location and want to navigate to a specific location. We thus present a novel, real-time, vision-based intelligent wheelchair system that avoids collisions and provides adaptive audio prompts to help blindfolded users navigate to specified destinations. Existing intelligent wheelchairs have used various active sensors (acoustic, sonar, infrared, laser, etc.) [6]. We rely solely on a stereovision camera due to its low power consumption, ability to perform in natural environments, and relatively low cost. Most outdoor wayfinding systems rely on GPS, which is unreliable in indoor settings, while indoor wayfinding systems typically use beacon and RFID technology, which require modifications to the environment. By using vision-based techniques we can achieve accurate localization, while reducing/eliminating the need for environment modifications. In addition, cameras capture and provide a richer dataset than can be used for high-level scene understanding to build maps and determine what type of room the wheelchair is in.

MATERIALS AND METHODS

The intelligent wheelchair system consists of a Nimble Rocket™ wheelchair, a 4mm Bumblebee® 3D stereovision camera, and a laptop computer placed under the wheelchair seat. The wheelchair consists of a customized controller, which sends signals from the laptop to the wheelchair, enabling/disabling motion of the wheelchair in specific directions. The modules below are integrated using the Robot Operating System provided by Willow Garage (http://www.willowgarage.com), which allows us to run multiple processes in a distributed fashion:

- *Collision Detector* - detects frontal collisions and stops the wheelchair if an object is detected within a distance of approximately 1 meter, preventing motion in the direction of the obstacle through the controller. Implementation details of this module can be found in [5].
- *Path Planner* – given a global map of the environment and an initial position estimate, visual odometry is used to estimate the current position of the wheelchair using [7]. Techniques in [8] are used to produce the optimal route to the specified goal location. The trajectory is analyzed to determine deviations from the optimal route as well as upcoming turns.
- *Prompter* – uses a Partially Observable Markov Decision Process (POMDP) to determine the optimal prompting strategy, similar to [9]. Specifically, this module estimates the users' levels of awareness (their ability to navigate to the goal independently) based on past errors, and responsiveness to prompts in order to select appropriate audio prompts to assist the users in navigation.

In order to test the system, we recruited four able-bodied participants with no previous wheelchair driving experience. They were shown a route in a realistic environment and required to navigate a powered wheelchair to the destination while blindfolded. The experiment consisted of two distinct phases, A and B. Phase A was conducted without the collision avoidance and navigation system (baseline), while the system was activated in Phase B. In order to ensure a balanced study, half (two) of the participants were randomly selected for A-B, and the remaining participants were assigned B-A ordering. The primary outcomes measured were number of frontal collisions, number of turns successfully completed (the route consisted of three turns in total), and maximum progress made towards the goal (determined by measuring the shortest distance to the farthest point along the optimal route reached by the user, and expressing it as a percentage of the total (shortest) distance to the goal).

RESULTS AND DISCUSSION

Table 1 shows the results of the primary outcomes measured for each participant. Participants 1 and 3 completed B-A ordering, while participants 2 and 4 completed A-B ordering.

Table 1. Primary outcomes for each participant

Participant ID	Phase A (baseline)			Phase B (intervention)		
	Collisions	Turns	Progress	Collisions	Turns	Progress
1	3	2	44.0%	0	3	100.0%
2	3	0	15.4%	0	3	100.0%
3	2	3	100.0%	0	3	100.0%
4	2	2	48.3%	0	3	100.0%

As seen above, the number of frontal collisions is lower when the system is activated, regardless of the phase ordering. In addition, the number of turns completed and progress made towards the goal is greater with the navigation system in most cases. Participants 1, 2 and 4 were unable to reach the destination without the system and stopped driving due to high levels of anxiety and confusion in the baseline Phase A. All participants completed the navigation task during the intervention Phase B and expressed a strong preference for the system due to higher safety and lower mental demand/stress.

Only a few false positive collisions were detected during the experiments due to glare from one of the windows in the test environment, suggesting the need for window detection in future prototypes.
We acknowledge that users with real vision impairments might perform differently from blindfolded users. However, we anticipate that our system can still benefit newly-impaired users. Preliminary trials of the system with users with dementia show that the system described in this paper is able to benefit cognitively-impaired drivers as well [10].

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AN ASSITIVE ROBOTIC TABLE (ART) PROMOTING INDEPENDENT LIVING

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INTRODUCTION

In hospitals, technology has become pervasive and indispensable during medical crises. At home, technology proliferates as computerized health monitoring systems and, perhaps in the future, as assistive "humanoid" robots. Meanwhile, our everyday environments remain essentially conventional: low-tech and ill-adaptive to dramatic life changes. This social condition places strain on healthcare and family support systems, and represents a failure of scientists, engineers and architects to support independent living.

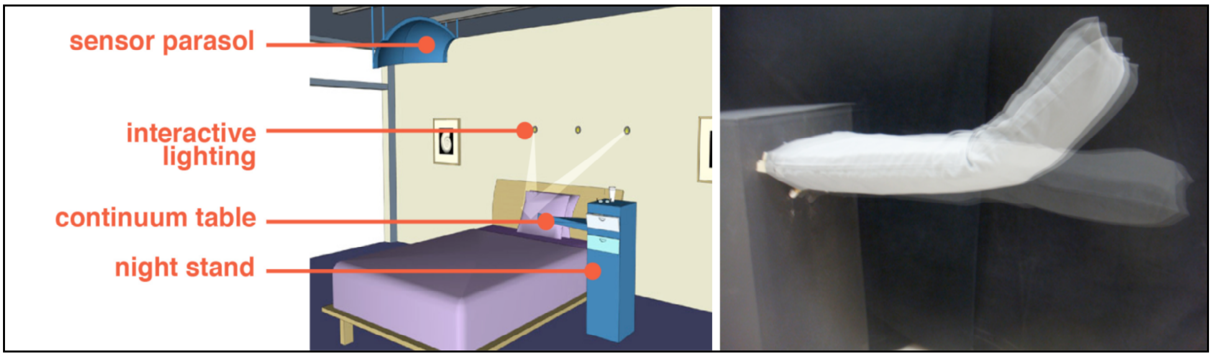

Fig. 1: Rendering of ART with key aspects identified; our working prototype of the continuum surface

How can our everyday environments be outfitted with intelligent hardware promoting independent living? We focus on a discrete component of an envisioned suite of networked, robotic furniture integrated into existing living environments: an Assistive, Robotic Table [ART]. ART is the hybrid of a typical nightstand and the over-the-bed table found in hospital rooms, comprised of four key components (figure 1): **a *smart night stand*** manages, stores and delivers personal effects, including medical supplies, and communicates to caretakers when eyeglasses and other belongings are not moved over a period of time. It accommodates audio and touch screen computing technologies; **a *continuum table*** gently folds, extends, and reconfigures to support work and leisure activities, retracts in emergency circumstances, and even retrieves everyday objects for users; ***interactive lighting*,** intended for installation behind the bed, sofa, or chair, allows for user control and intelligent control of task lighting (on/off, dimming and direction); and **a *sensor parasol***, ceiling suspended, tracks intimate human needs and capabilities. Physically, we envision this novel "sensor parasol" as allowing for detection of human behaviors in an intimate living space (e.g. near and around bed, sink, reading chair) without resorting to invasive cameras and body-worn sensors. These components of ART recognize, communicate with, and partly remember each other in interaction with human users and with other components of the envisioned suite.

DESIGN APPROACH AND SCENARIO

ART features a novel continuum-robotic surface (figure 1 – right image) [1],[2]. While the traditional approach to providing movement in both robotics and architectural design relies on rigid structures (e.g. links, axles, doors, and windows) along, or about one-dimensional surfaces (i.e. lines and axes), we argue for an alternative design approach based on a flexible, continuous two-dimensional surface actuated by pneumatic muscles – a new and emerging technology for assistive robotics. Such a compliant surface promises to achieve the simultaneous flexibility and load capacity required for ART and meet its design constraints, while ensuring that users are safe and comfortable with, and accepting of the technology.

The key deliverable for this research is the full-scale, working ART prototype performing "Going-to-bed" and "Getting-out-of-Bed" scenarios for three target groups. In the "Getting out of Bed" scenario, Andrea, a 58-year-old English Professor living independently and actively, is in a hospital room following her treatment from a fall from which she sustained a shoulder injury (fig. 3 – LEFT). ART considers such context as time of day, Andrea's personal data, and in a novel way, her behavior at close range via the sensor parasol. Using this information, the system detects Andrea's activities and gestures to plan and execute appropriate responses, as follows:

User	Hardware System	Software System	Scenario Step
		1	ART initiates its morning reminder service for family visits, nephew's birthday, etc.
	2		ART displays the day's appointments: Dr. visit, nephew's birthday, etc.
3			Andrea decides to read for a while before beginning her day. She gestures for the novel she has been reading (overriding system expectations).
	4		ART's nightstand component senses the gesture.
		5	ART locates the stored novel in its inventory.
	6		ART's nightstand retrieves the novel and extends the overbed table to offer it to Andrea.
7			Andrea reaches for the book. She reads for twenty minutes to complete the previous night's chapter and then replaces the book.
	8		ART's nightstand component stores the book.
		9	ART logs the location of the stored novel.
		01	ART plays a prerecorded message from Andrea's young grandchildren which she enjoys.
		11	Previous data show a decline in mobility.
	12		The bed lowers to facilitate Andrea's transition to a standing position
13			Andrea gets out of bed

Fig. 2. ART and "Andrea": Getting-out-of-bed during a hospital stay; and Going-to-sleep at home.

DISCUSSION

To facilitate aging-in-place, it is important to re-think the environment in which we live. While there is previous work in adaptable housing for aging in place (e.g. Universal Design), and specific applications of intelligent machines to aging in place (e.g. Humanoid Robots), the thrust of this work represents a departure from other approaches: the creation of intelligent, adaptive, physical-digital environments for aging in place. *ART features intelligent behavior and "architectural robotic" elements in contrast to more typical assistive technologies or medical robotics designed as substitutes for people*. We envision ART as integral to one's living space. ART aims to augment the domestic interior to become a more inviting, responsive and accommodating environment for living independently, encouraging inhabitants to do tasks for themselves, yet providing assistance when needed.

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Evaluation of the Impact of Force Control and Motion Laws in rehabilitation

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INTRODUCTION

The study investigates the impact of robot trajectories, i.e. motion paths and laws, on users' perception and muscular activity. A fundamental assumption of motor learning is that repetitive movement practice improves motor functions [1][2][3]. Type of movement, imposed velocity, balanced guiding-force and level of muscular activity are in fact likely to play a key role in the rehabilitation process. The presented experimental setup is used to test different force and velocity control modes, along different 6D trajectories at natural motion speed, possibly in interaction with a virtual environment.

MATERIALS AND METHODS

Equipment: an industrial-class redundant manipulator (Mistubishi PA10), able to provide 1.5kw and max. 1.5m/s; a 6 TVC 3D-motion tracking system coupled with wireless EMG (BTS Smart-D with FreeEMG); a safety inertial device; a Virtual Reality (VR) environment.

Force control: the robot control combines a force balance (Figure 1) resulting from the forces exerted by the user $\mathbf{f}_h$ and the resultants of the VR dynamics $\mathbf{f}_{VR}$. The balance force $\mathbf{F}_{tot} = \lambda_1(d)\mathbf{f}_h + \lambda_2(d)\mathbf{f}_{VR}$ - where d is the compenetration of bodies in the VR – triggers an admittance-like control through a non-linear friction model c_1, c_2

$$\ddot{\mathbf{x}} = \frac{\mathbf{F}_{tot} - \left(\mathbf{F}^0 + c_1\dot{\mathbf{x}} + c_2\dot{\mathbf{x}}^2\right)}{M} \quad (1)$$

where $\mathbf{x}$ is the robot TCP. The model in Eq. (1) represents the general control framework for (i) rendering a haptic feedback from the VR; (ii) providing a gravity-compensated manual guidance to the user; (iii) providing interaction dynamics also for robotic platforms with no direct access to torque control; (iv) mixing the VR and user interactions through λ_1, λ_2.

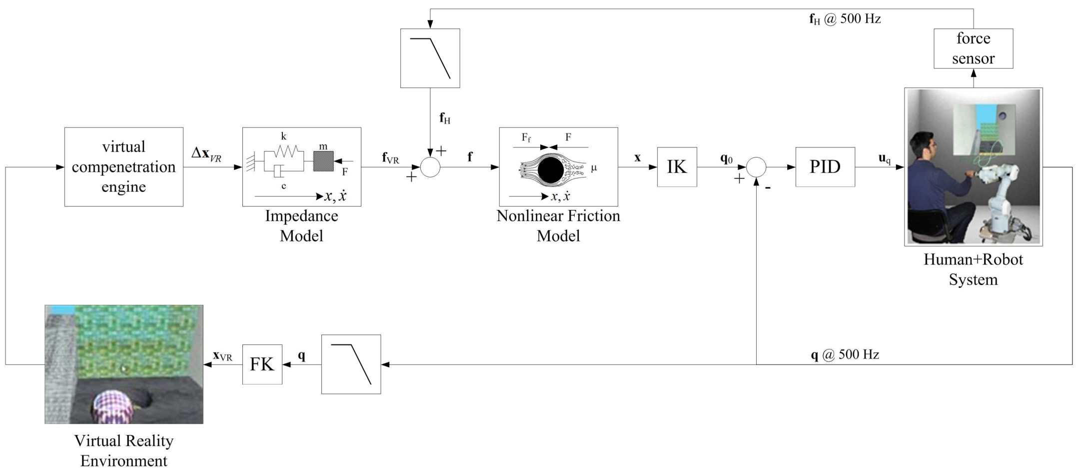

Figure 1. Interaction control between the user and the VR environment: on the right-hand side, the fast robot joint position control; on the left-hand side, the slower impedance control for VR dynamics. The Cartesian force reference is processed by a nonlinear friction model. IK (FK) inverse (forward) kinematics and force filters are also depicted.

Trajectories: a spline-based description of 6D paths and motion laws allows the execution of ADL functional rehabilitative trajectories.

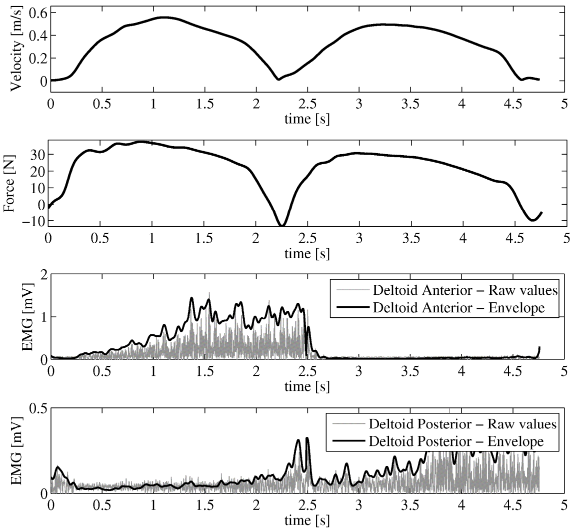

Figure 2. Force control along constrained path.

One comprehensive test case for interaction control and the evaluation of impact of motion profiles is when the robot can be constrained to the path but the motion law depends on the forces exerted by the patient (see Figure 2). The force control and the friction model are blended with a weighted linear combination of the force exerted $\mathbf{f}_h$ and a motion law $v_d(t)$ stored/computed

$$\ddot{s} = \xi_1(\|\mathbf{f}_h\|)\frac{\|\mathbf{f}_h\| - \left(\mathbf{F}^0 + c_1\dot{s} + c_2\dot{s}^2\right)}{M} + \xi_2(\|\mathbf{f}_h\|)\dot{v}_d \,. \tag{2}$$

Table I. Tunable Parameters

trajectory and interaction	
trajectories	
path	$s(t)$
velocity	$v_d(t)$
max forces	$\bar{\mathbf{f}}_h, \bar{\mathbf{f}}_{VR}$
virtual environment	
object mass	m
stiffness	k
damping	
gravity	c
scale factor	
balance coefficients	λ_1, λ_2
robot outer force ctrl	
object mass	M
stiffness	K
friction	c_1, c_2
force field	$\mathbf{F}^0$
directions	$\mathbf{n}, \mathbf{t}$
forces	$\|\mathbf{f}_h\|$
balance coefficients	ξ_1, ξ_2
robot inner velocity ctrl	
PID gains	

The control of the force along the path allows the user to perform smooth movements (see Figure 2).

Evaluation of impact of paths and motion laws. Subjects (6 healthy, 29±5 yrs, 1F) were requested to perform 12 consecutive robot-assisted reaching movements[4]. Movements were derived from combinations of rectilinear/natural paths $s(t)$ and constant/natural velocities $v_d(t)$. Displacement of a weightless robot was allowed by the force control model in Eq. (2). At the end of each trial the subject was asked to score the executed task according to a 5-point Visual Analog Scale (VAS) on how natural the movement was felt. EMG of shoulder and elbow joint muscles, upper-limb kinematics and dynamics were also computed.

RESULTS AND DISCUSSION

Preferred natural path and velocity profile in reaching movement (higher VAS scores, $p<0.05$) are used for evaluating the shoulder torque and co-contractions. Biomechanics shows that the free reaching is characterized by a lower maximum shoulder torque ($p<0.05$) due to an optimal conversion of the limb rotational kinetic energy into the potential one. Co-contractions decrease in the robot-assisted exercises when subjects actively provide energy in moving the robot along constrained paths. These results raise new questions about the importance of trajectories and laws of motion during robotic training, especially when high functioning patients are treated.

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NEW ROBOTIC TREATMENT SYSTEMS FOR CHILDHOOD CEREBRAL PALSY and AUTISM

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ABSTRACT

We present two assistive robots being developed at the MultiScale Robotics and Systems Laboratory (μRSeL) at The University of Texas at Arlington, and preliminary experimental results aimed at the treatment of certain motor and cognitive impairments for children with special needs.

In the Neptune project [1], we are configuring a mobile manipulator designed as an assistive device for the rehabilitation of children suffering from Cerebral-Palsy. Neptune consists of a mobile robot base and a 6DOF robotic arm, and it is interfaced to users via Wii Remote, iPad, Neural Headset, a camera, and pressure sensors. These interfaces allow patients, therapists and operators to interact with the robot in multiple ways, as may be appropriate in assistive scenarios such as: direct physical interaction with the iPad, arm positioning exercises through WiiMote, remote navigation and object retrieval through the environment via the Neural Headset, etc.

The RoDiCA project [2] (from Human-Robot Interaction System for Early Diagnosis and Treatment of Childhood Autism Spectrum Disorders) focuses on treating cognitive impairments in children suffering from ASD. The technological hypothesis of the project is that a life-like robot, in both appearance, and modality of interaction, will be considerably more effective in diagnosis and treatment of autism than conventional questionnaire-based systems, or other systems based on video and audio observations. Zeno is a robotic platform developed by Hanson Robotics for several years, based on a patented realistic skin, and it is currently unmatched in the marketplace. Zeno's aestetics form the starting point for RoDiCA, which is adapting Zeno for interaction with ASD sufferers, by upgrades including touch sensors on the robot hands, and an embedded control system. In the near future, its software will be able to perform 60 Hz (perceived real-time) subject tracking, advanced head-eye and hand coordination, gesture recognition and synthesis, data logging and analysis.

ADVANCED SOCIAL HRI WITH ZENO ROBOKIND

The Robot Zeno is based on a fictitious character - he looks like a 4-7 year old child, and its head is about ¼ of a size of an adult human head. Its unique features include life-like skin made of Frubber™ material, and its appearance is a game changing experience that seems to bridge Mori's uncanny valley. The work presented here builds on prior work on human robot interaction [3] to create a framework that assists therapists. Our goal is to create a system capable of interacting with human subjects undergoing therapy in a realistic and engaging manner. The system is capable of identifying, tracking and maintaining eye contact with the subject enabling an engaging interactive experience. Toward this aim, we present visual human tracking results obtained with the Zeno robot by coordinating its head and eye motion, so that the robot gaze appears natural. A reinforcement learning scheme (Temporal Difference), combined with visual servoing was used to balance the overall head and eye motion of the robot. Experimental results show that proposed HRI algorithm enables Zeno to achieve natural head-eye coordination with significant improvement in accuracy without the need of extensive kinematic analysis of the system. During

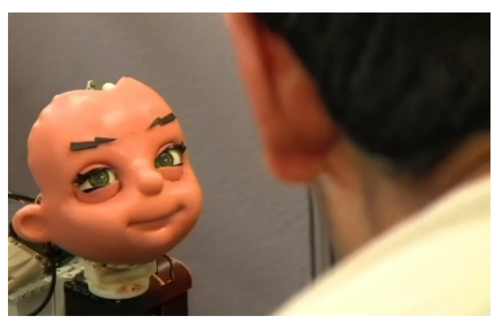

Figure 1. Zeno tracking human subject.

conversation with children and adults, the system managed to keep the subjects engaged when exhibited to a general audience.

PHYSICAL HRI WITH NEPTUNE

The Neptune robotic system is intended to speed up the rate of improvements during rehabilitation exercises for children with CP. One of the goals is to make it easier for therapists to administer treatment sessions, for instance in offering aid with the robot during the session through holding the iPad and adjusting its position from time to time. As a result, more sessions can be conducted by patients, in their home, leading to, we postulate, better treatment results. Another goal of the device is to allow recognition of select child hand motions through a WiiMote, and head/face motion through a brain-computer interface. Beneficial motions can then be rewarded through verbal or visual playback.

A picture of Neptune is shown in Figure 2. The Neptune robot consists of a mobile robot base, the LABO-3™, and a 6 DOF robotic arm – the Harmonic Arm™. The arm is interfaced to the base or to an external PC using Ethernet. Interaction algorithms run on the base PC using ROS or on an external Windows laptop via a Visual Studio application integrating different sensor/actuator components. In addition to the robotic hardware, we have custom interfaced it through a Wii™ Remote, an EPOC™ Headset, and an iPad tablet instrumented with four Flexi Force™ sensors. We present experimental results of interaction with the robot using each of the three HRI modalities, including physical contact [4].

Figure 2. Neptune with iPad and Flexi Force sensors mounted on the Ipad Tablet

The Nepune robot is at the stage where it can begin interacting with patients. Since children, including those suffering from CP stand to benefit from game therapy, we are quite excited to use iPad therapeutic games in conjunction with the robot. We plan to test the robot with CP patients during clinical trials with collaborators from Cook Children's Northeast Rehabilitation Center, and University of North Texas Health Sciences Center, both located in Dallas-Fort Worth region of the United States.

ACKNOWLEDGEMENT

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Workshop on "New and Emerging Technologies in Assistive Robotics" – IROS 2011
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NOVEL SELF-FEEDING ROBOT FOR KOREAN FOOD

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INTRODUCTION

We introduce a newly designed self-feeding robot that will be suitable in the case of Korean food, including sticky rice. The self-feeding robotic system allows people who have disabilities of upper limbs to eat the chosen food when they want it. Most feeding systems scoop the food with a spoon. Those systems are not suitable for use in the case of boiled rice, which is a staple food in Korea. In addition, some systems have a single dish, and thus different types of food might be mixed during scooping. My Spoon uses the grasping function to pick up food, but this system has difficulty serving Korean rice due to its fixed grasping strength and the grasping openness of the gripper. As a result, My Spoon's gripper sometimes gets a lot of rice attached to its surface. Other self-feeding robotic systems also have difficulty scooping this staple Korean food.

We developed an assistive robot for self-feeding by taking into consideration the feedback of user candidates and clinical experts. We evaluated the self-feeding robot by performing a series of user tests. The overall process, i.e., formulating a concept, design, and evaluation involves feedback from users and clinical experts. The development process is performed on the basis of the philosophy of participatory action design [1].

The primary users of self-feeding robots are people with physical disabilities who have difficulty moving their upper limbs. Such people include those suffering from high-level spinal cord injuries, cerebral palsy, and muscular diseases. We can also include senior citizens who have difficulties with the motor functions of their upper limbs, e.g., the fragile elderly, among the abovementioned disabled people. It is clear that the number of overall target users of self-feeding robots will be growing in the near future.

Figure 1. New assistive robot for self-feeding (left-hand side). Spoon-arm (Arm #1) uses a spoon to transfer the food from a container to a user's mouth. Grab-arm (Arm #2) picks up the food from a container and then loads it onto the spoon of Arm #1. The self-feeding robot in a single arm configuration (right-hand side).

MATERIALS AND METHODS

The major findings of the survey are as follows [2, 3]. Firstly, a user should be able to control the feeding interval for the desired food. In the case of caregiving, one of the common problems is the difficulty in controlling the feeding interval. People with cerebral palsy have difficulty representing their intentions quickly when the feeding interval is too short. Secondly, the specialists and the user candidates believe that the feeding systems are designed more for western-style food. Those systems are not suitable for Korean food, which includes boiled rice, soup, and side dishes. Thirdly, a feeding robot should be suitable for use in private homes and facilities. Next, the location of bowls or a tray is another important factor.

We have developed a simple robotic system that has a dual-arm manipulator that can handle Korean food such as boiled rice in an ordinary food container, as shown in Fig. 1. We divide a self-feeding task into two subtasks: picking up/releasing food and transferring food to a user’s mouth. The first robotic arm (a spoon-arm, Arm #1) uses a spoon to transfer the food from a container on a table to a user’s mouth. The second robotic arm (a grab-arm, Arm #2) picks food up from a container and then puts it on the spoon of a spoon-arm. The two proposed arms with their different end-effectors mimic Korean eating behavior. Specifically, Koreans use a spoon and steel chopsticks during mealtime. A spoon-arm has two degrees of freedom (DOF). A grab-arm includes a three-DOF SCARA joint for the planar motion, a one-DOF prismatic joint for the up and down motion, and a gripper. The overall number of DOFs of a dual-arm without a gripper is six.

We observed that releasing rice is as important as picking up rice. The stickiness of the boiled rice can change depending on its temperature. Slightly cool rice is difficult to release from the gripper. In order to solve this problem, the feeding robot automatically puts the gripper of the grab-arm in water before grasping the food. The water is located in a bowl next to the rice. When this is done, the gripper can release the rice on the spoon because the stickiness of the rice has decreased.

The amount of rice picked up is adjusted on the basis of actual experiments on rice grasping. A gripper’s mechanism is the simple opening/closing of gripper fingers via a linear actuator. The weight of the rice corresponding to one grasping motion increases depending on the open/close width of the fingers of the gripper when grasping begins. The close width of the gripper makes the grasping force to food. Thus, we can grasp various foods by adjusting the open/close width of the gripper.

We built two arm configurations of the developed self-feeding robot: a dual-arm configuration and a single-arm configuration. A dual-arm configuration follows an original design concept using both a spoon-arm and a grab-arm. A single-arm configuration uses only the spoon-arm, and a caregiver takes the role of the grab-arm. A spoon-arm could be used independently without a grab-arm. From an economical point of view, the single-arm configuration has a lower cost in comparison with the dual-arm configuration.

RESULTS AND DISCUSSION

We carried out the user tests with user candidates, including seven people with spinal cord injuries. After they actually ate food using the developed self-feeding robot, we collected their feedback to determine their satisfaction score in accordance with input devices. Average scores of buttons and joysticks are 2.7 and 7.6, respectively (score 1-10, 10 is highest level of satisfaction). The users ate food using the self-feeding robot with each of the input devices. The results of the users’ feedback pertained to the self-feeding robot as well as the input devices.

Comparison results show that the developed system is effective to handle Korea food. Four users rated their performance on a scale of 1 to 5. The performance score of a developed system and a commercialized feeding system, My Spoon, are 4.3 and 3.0 (Score: 1-5, 5 is highest level of performance), respectively.

Most of the users who participated in the experiments gave us positive feedback. Some users were impressed that they were able to eat their desired food when they wanted to eat it. The proposed robot has three distinguishing points: handling sticky rice, using an ordinary meal tray, and a modular design that can be divided into two arms. Specifically, the grab-arm could be used alone if a caregiver picks food up on the spoon of a spoon-arm. We have developed a novel assistive robot for self-feeding which strongly depends on the culture of users. This robot could be an exemplary assistive robot which is related to the culture.

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AROUND THE WORLD WITH PARO: CHALLENGES IN DESIGNING AND USING ASSISTIVE ROBOTS ACROSS CULTURES

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INTRODUCTION

This paper reviews literature from cultural psychology and human-robot interaction and uses the seal-like robot PARO as a case study to describe cultural factors that can affect the acceptance and use of socially assistive robots (SARs) and propose a culturally comparative research agenda and framework that is generally applicable to the field. PARO is a seal-like robot developed to simulate pet therapy and produce mental, physical and psychological benefits in users, which include older adults with various levels of cognitive and physical impairment [1]. PARO was initially developed and evaluated in Japan and is currently used in thirty countries around the world; it became commercially available in Japan in 2005 and in Europe and the US in 2009. PARO's therapeutic effects have been studied in multiple countries, but there has been little comparative research about user acceptance and practices. Surveys in Europe and Asia suggest cultural variability in the way people initially perceive PARO: while user impressions are positive overall, European users focus on PARO's similarity to a real animal, while users in Japan and South Korea emphasize its interactive capabilities as the most positive trait [2].

CULTURAL MODELS IN THE ACCEPTANCE AND USE OF SARS

Research in cultural psychology suggests “cultural models” [3]— “presupposed, taken-for-granted models of the world that are widely shared” by the community (p. 4)[4]—can be salient factors in the perception and use of socially assistive robots. Culturally variable *social-behavioral models*, which define the rules for engaging in and interpreting social actions, and *socio-technical models*, which refer to technology's meaning and role in society [3], can affect how users adopt and use SARs.

PARO's therapeutic effects rely on tactile interaction and social cues such as vocalization and gaze [1] and an associative function, which encourages people to relate PARO to memories of prior experiences they find meaningful [5]. How users interpret these cues can differ according to cultural expectations. The analytical focus on relationships and context in Asian societies [6] suggests the way PARO is situated within the community may be an important variable in patient's acceptance and interpretation of the robot in Japan. Western users may be more prone to “paying attention primarily to the object and the categories to which it belongs” (p. 291)[6], so whether PARO is introduced as an animal or technology and the expectations users have of those categories should have salient effects.

Sociotechnical models referring to technology's role in society can also play a role in users' perceptions of robots. In Japan, robots are construed as “partners” to be integrated into everyday life, while in the US they are “second selves” that can simulate and replace humans [7]. Users in Japan can be expected to develop a more relational understanding of the robot as a creature in their environment (see Figure 1). Users in the US, on the other hand, may be more likely to project their own characteristics onto PARO, as was noticed by Turkle [5] in what she calls the “Rorschach effect.”

Cultural norms pertaining to the roles and behavior of users can also affect the way people react to and use the robot. Researchers have found that women are more likely to use PARO than men [8]. However, the majority of users of SONY's dog-like robot Aibo were male [9]. One reason for this may have to do gender norms: Aibo's metallic angular body has a more “techy” appearance which fits male stereotypes, while soft round PARO seeks to inspire nurturing interactions that call upon female stereotypes. In order to make PARO more acceptable to male users, it may be useful to emphasize its robotic nature. In studies with Roomba, Forlizzi [10] showed that using the robotic vacuum made cleaning, generally coded as female work, more attractive to men and teens.

Figure 1. PARO is situated within its own “house” in a Japanese nursing home; Turkle [5] suggests that US users project their own experiences onto PARO, “comforting themselves” as the comfort the robot.

Finally, the institutional context in robots are used can also affect the perceptions, use, and acceptance of users [11]. The institutional setup of care varies from country to country: nursing facilities in Japan, whether public or private, are similarly equipped and staffed, while nursing facilities in the US can vary widely in terms of funding, equipment, staff training and ratio of staff to patients. PARO is also used with patients who have varying levels and types of cognitive and physical function, including individuals with dementia and autism. The former have a documented affinity to robots [12], so introducing PARO as a machine and using it as a mediator to scaffold social interaction and social skill development may be more effective than focusing on its pet-like qualities.

DEVELOPING CULTURALLY SITUATED GUIDELINES

Wada et al [8] have developed a set of preliminary guidelines caregivers can use in therapeutic interactions between users and PARO through observations in five facilities in Japan. These guidelines need to be extended to include practices for facilities in other countries, facilities of different types (private v. public, care home v. nursing home), care givers with varying levels of expertise, and patients with different levels and types of cognitive and/or physical decline. The abovementioned cultural and institutional factors relating to the use of SARs, in our case the seal-like robot PARO, define our program for designing and evaluating robots across cultures. The main questions we focus on are: *(1) how users apply and respond to different socio-behavioral models of robots* (e.g. PARO as robot, pet, or partner); (2) *how users perceive and respond to socio-technical models of the robot* (e.g. relational/utilitarian, companion/replacement); (3) and *how robots are and should be used in different institutional settings* (e.g. what are current practices and possible improvements).

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Invited talk session II

KNEXO: a Knee Exoskeleton to test design and control concepts for gait rehabilitation.

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A powered KNee EXOskeleton (KNEXO) has been designed, built and evaluated in order to study different design and control concepts in support of the development of a bilateral lower limb exoskeleton [1]. This prototype serves as an evaluation platform for a specific lightweight variable compliance actuator, the pleated pneumatic artificial muscle (PPAM, [2]), and for suitable control strategies that ensure safe and compliant physical human-robot interaction (pHRI) in a gait rehabilitation setting. The latter has been evaluated in robot-assisted walking experiments with several unimpaired subjects, a stroke patient and a multiple sclerosis (MS) patient.

KNEXO (see fig. 1) consists of an upper and lower leg link interconnected by a 1 DOF joint at the knee, and an adjustable interface for individual fitting. The device is wall-grounded through a 6 DOF gravity balancing supportive arm for passive compensation of the exoskeleton's weight (4.5 kg) while ensuring sufficient mobility during treadmill walking. The actuator system has been designed in view of full knee support at moderate walking speeds. The novelty with respect to other pneumatic muscle based rehabilitation devices is the use of four bar linkages for optimised actuator force transmission to the joint ensuring a high torque output and a large range of motion. KNEXO provides peak extension and flexion torques of 75 Nm and 60 Nm respectively and a range of motion of 90°.

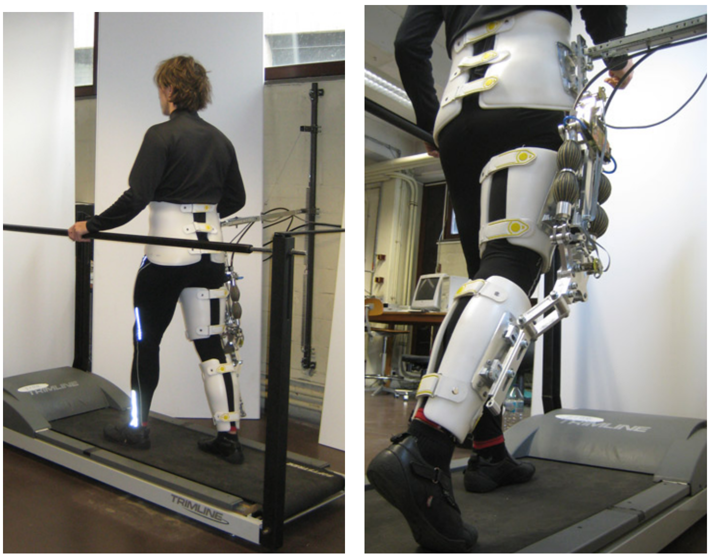

Fig. 1: Knexo

Two modes have been implemented: a zero torque (ZT) mode, as a baseline for performance evaluation and for reference knee pattern recording, and an assistive mode for safe and compliant guidance along a target knee pattern. The zero torque mode relies on a PI torque controller with force sensor based torque feedback to minimize residual actuator torques (<3 Nm). The assistive mode uses Proxy-based Sliding Mode Control (PSMC, [3]) as an interaction-oriented trajectory control strategy. PSMC combines responsive PID-like tracking performance with an adjustable actuator torque limitation and under torque limitation it ensures an adjustable slow recovery from large trajectory deviations. In prior work this behaviour was shown to improve safety in human-robot impacting contact [4] and to be suitable for low force kinaesthetic guidance [3]). To improve the torque limitation accuracy of PSMC in KNEXO, the torque controller has been implemented as an inner torque control loop. With a peak-to-peak torque of 50 Nm at 4 Hz the torque controlled actuator system can provide full knee support at moderate walking speeds and as such it outperforms several other pneumatic muscle based assistive devices.

Interaction experiments with unimpaired subjects demonstrated that KNEXO is capable of providing compliant guidance along various knee trajectories and displaying different assistive modes. Since control parameter tuning requires a trade-off between safety of interaction (torque limitation) and safety of guidance (preventing a fall), guidelines were extracted in view of patient testing. Both in the stroke patient and the MS patient assistance by KNEXO had a direct effect on knee function and on gait symmetry. The patient's right knee kinematics were marked by a hyperextension (overstretching) during stance and an unsmooth and slow extension during swing, as can be observed in Fig. 2 (PRE, red). With the KNEXO this was improved (assisted, purple). In the MS patient weight bearing considerably increased at the assisted side leading to improved left-right heel strike timing symmetry. This was confirmed by gait analysis and also by patient feedback on perceived assistance and comfort. Considering these promising results, the benefits for pHRI of the torque saturation and slow recovering motion of PSMC should be further explored in specific interaction scenarios (e.g. stiff knee gait, spasticity). Future work is the development of a full lower limb exoskeleton.

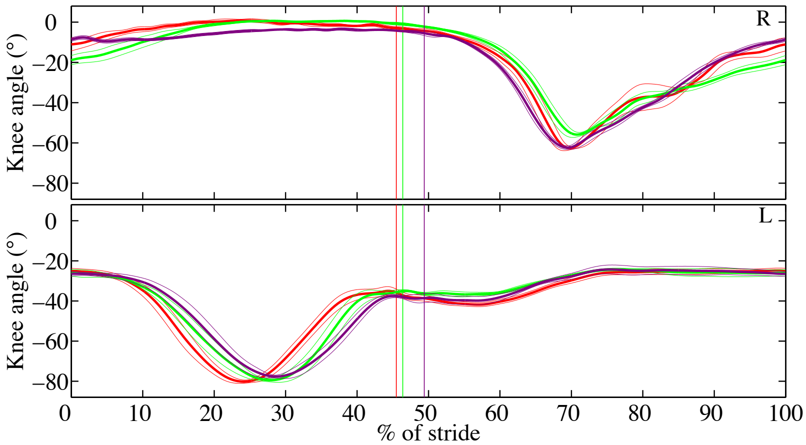

Fig. 2: Gait kinematics: flexion/extension angles of the patient's right and left knee joint without KNEXO (PRE, red), with KNEXO unassisted (ZT, green) and assisted (PSMC T1 100%FF 50%G, purple)

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Human Assistive Robot Systems Controlled by Servo Brakes

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1 Introduction

As societies age and experience a shortage of people for nursing care, handicapped people, including the elderly and blind, find it increasingly necessary to be self-supporting. However, many such people suffer from injuries, poor eyesight, or a general lack of muscular strength, and need the support of other people in daily activities. In recent years, we expect to utilize robot systems not only in industrial fields, but also in homes, offices and hospitals in cooperation with humans. Many robot systems have been researched to realize a physical support for human being.

This article especially focuses on a walker-type support system and a motion support system which work on the basis of the physical interaction between the systems and the user. Many intelligent systems based on robot technologies consist of servo motors and sensors such as force/torque and ultrasonic sensors. Information from many types of sensors controls the servo motors. By appropriately controlling the servo motors, these intelligent systems provide many functions, such as variable motion, obstacle avoidance, and navigation; thus, they provide a maneuverable system.

In this article, we consider a passive intelligent systems, which are not only simple structure and safe but also offers many functions similar to those found in active systems. We develop a passive intelligent walker called the RT Walker that uses servo brakes and incorporates passive robotics. We also extend it to a passive motion support system used for rehabilitation and sports training.

2 Passive Robotics

For practical use of intelligent systems in the real world, we need to consider two main points: achieving high performance and user safety. Most conventional intelligent systems have servo motors that are controlled based on sensory information from sensors such as force/torque sensor, laser range finder and ultrasonic sensor. The high performance of intelligent systems is realized in the form of functions such as power assistance, collision avoidance, navigation, and variable motion.

However, if we cannot appropriately control the servo motors, they can move unintentionally and might be dangerous for a human being. In particular, in Japan, legislation must be formulated for using them in a living environment. In addition, active intelligent systems tend to be heavy and complex because they require servo motors, reduction gears, sensors, a controller, and rechargeable batteries. Batteries present a significant problem for long-term use because servo motors require a lot of electricity.

Goswami et al. proposed the concept of passive robotics [1], in which a system moves passively based on external force/moment without the use of actuators, and used a passive wrist comprising springs, hydraulic cylinders, and dampers. The passive wrist responds to an applied force by computing a particular motion and changing the physical parameters of the components to realize the desired motion. Peshkin et al. also developed an object handling system referred to as Cobot [2] consisting of a caster and a servo motor for steering the caster based on passive robotics.

Wasson et al. [3] and MacNamara et al. [4] proposed passive intelligent walkers. In most of these walkers, a servo motor is attached to the steering wheel, similar to the Cobot system, and the steering angle is controlled depending on environmental information. The RT Walker introduced in this article also has passive dynamics with respect to the force/moment applied. It differs from other passive walkers in that it controls servo brakes appropriately without using any servo motors.

The passive concept could be applied to a motion support system such as haptic devices. An arm-type passive haptic device has been proposed by Koyanagi [5]. In addition, a passive arm with dynamic constraints (PADyC) has been proposed as an assistant tool for surgeons [6]. Based on the Cobot architecture, applications of a haptic display have been proposed [7]. Dissipative haptic devices using either brakes or clutches have been developed to dissipate or redirect energy in the required direction [8][9][10]. In this article we also introduce a passive motion support system controlled by servo brakes.

These passive systems are intrinsically safe because they cannot move unintentionally under a driving force. The passive robotics will prove useful in many types of intelligent systems for supporting the human motion based on the physical interaction between the systems and humans.

3 Passive Intelligent Walker [11]

3.1 Hardware

In this research, we pay special attention to the braking system, and propose a new passive intelligent walker (RT Walker), which uses servo brake control. The servo brakes can navigate the RT Walker, and its maneuverability can change based on environmental information or the difficulties and conditions faced by the user.

The developed RT Walker is shown in Fig.1. This prototype consists of a support frame, two passive casters, two wheels with servo brakes (referred to as powder brakes), a laser range finder, tilt angle sensors, and a controller. The part of the rear wheel with the powder brake is shown in Fig.1; the brake torque is transferred directly to the axle. The brakes change the torque almost in proportion to the input current.

RT Walker is lightweight because its structure is relatively simple compared to active intelligent walkers, and it needs little electricity to operate the servo brakes. The driving force of the RT Walker is the actual force/moment applied by the user, and therefore, he/she can move it passively without using the force/torque sensor. By changing the torque of the two rear wheels appropriately and independently, we can control the motion of the RT Walker, which receives environmental information from its laser range finder and tilt angle sensors. Based on this information, the RT Walker can realize the collision avoidance, gravity compensation, and other functions.

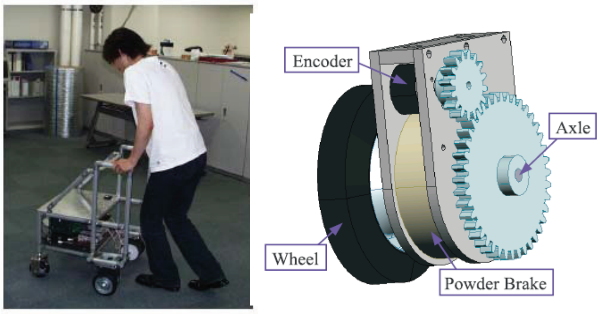


Fig.1 Passive Intelligent Walker -RT Walker-

3.2 Environmentally Adaptive Motion Control

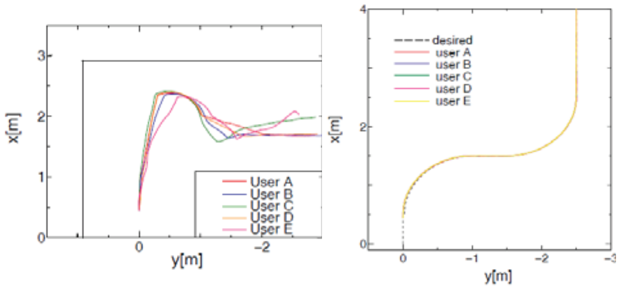
When we use intelligent walkers in living environments, we must consider motion control algorithms based on information about the environment. In particular, in environments with differences in the street level, stairs, or many obstacles or slopes, using walkers safely and smoothly requires environmentally-adaptive motion control.

In this section we consider a navigation function so that many people including blind people could also use these walkers as navigation system for guiding the user to a destination. In this article, we apply the virtual force/moment generated from the environmental information, and control the brake torques based on this virtual force/moment.

Experimental result is shown in Fig.2. Fig.2(a) shows the path of five ordinary people detected by the encoder system of the RT Walker. You can see that five people moved without colliding with the wall along the environment. We also experimented with a path leading from a start point to a destination. In this experiment, we generated an S-line path for the RT Walker using the artificial potential field, which can generate the potential with a steep gradient. In this experiment, five university students with blindfolds operated the RT Walker. The results are shown in Fig.2(b), and the differences between the desired and actual paths were almost zero; path following was successfully achieved.

we also consider gravity compensation. If we compensate for gravity using the servo brakes, the walker will not move on a slope, unless the user applies intentional force/moment. Thus, the user could use the RT Walker as if it is always on a horizontal plane. Gravity compensation of the RT Walker is an important user safety function.

We tested the RT Walker in a real-world environment, as shown in Fig.3. Although the user did not touch the walker, which was either on a downhill or uphill road, it did not move because of the force of gravity. That is, it only moved when the user intentionally applied force to it, just as if it was always on a horizontal road. Note that the RT Walker cannot pull the user against gravity when walking uphill, which makes it different from active walkers. This is the disadvantage of the passive walker. However, when walking uphill, the user's load is less, because the passive walker is relatively lightweight and is not pulled downward by gravity.



(a) Obstacle Avoidance (b) Path Leading

Fig.2. Experimental Results of Navigation Function

(a) Experiments Going Downhill

(b) Experiments Going Uphill

Fig.3. Gravity Compensation Function

4 Passive Motion Support System [12]

4.1 Wire-type System Controlled by Servo Brakes

The haptic device is one of the robot systems that could realize the physical support for human being. Haptic devices are expected to apply to virtual reality, rehabilitation, sports training, and so on. They could display a force to user of those devices. In sports training and rehabilitation, especially, system realizes physical support for human to improve the motion of users. For example, sports trainers support motion of players physically, when they teach perfect form. Caregivers also support motion of patients in rehabilitation of the handicapped. In above situations, haptic devices could support human motion physically by displaying forces to users. Many researchers have researched haptic devices based on various themes. Most of the haptic devices researched so far are driven by servo motors. Although haptic devices with servo motors are useful for realizing the several functions, they have serious potential to injure its operator if we cannot control the servo motors appropriately.

In the concept of passive robotics, some researchers have proposed the arm-type passive haptic devices which move passively based on external force without using any servo motors. These passive systems are intrinsically safe because they cannot move automatically with driving force. However, the large scale arm-type haptic devices affect the high-speed operation of them because of their large inertia. If we need large operating range and high speed operation of the system in such as sports training, arm-type haptic device could not suitable for the physical support of the human motion.

On the other hand, wire-type haptic devices realize large operating range and high speed operation, because of its small inertial effect. In this research, we develop a new passive haptic device which consists of wires with servo brakes for physical support of human being. This system is intrinsically safe and has wide operating range. However, the control of system using wires with servo brakes is challenging, because servo brakes cannot generate driving force and wires generate only tension. If we control this system based on the concept of passive robotics, it is useful for physical support of human motion with keeping the safety and wide operating range.

4.2 Hardware

We develop a motion support system using four wires with servo brakes as shown in Fig.4 for investigating the possibility of wire-type passive haptic device. It is controlled the position of the handling point on plane. The system consists of four brake units, four wires, aluminum frames and a controller. We control the motion of handling point which is the intersection of wires.

The brake unit is shown in Fig.4. The brake unit consists of a powder brake, a constant force spring, an encoder, a pulley, three gears and a wire. We used powder brake as the servo brake. It provides high response and good linearity on controlling the braking torque of brake units. The wire pulled out from the brake unit and reeled. A braking force transmitted from the powder brake to the pulley through gears. We have to apply tensions to wires in order to control motion of the handling point of the system. However, the powder brake cannot reel in the wire because it cannot generate driving force. To overcome this problem, the constant force spring apply a constant tension to each wire and handling point is balanced through the wires with constant tensions. The constant force spring can reel in a wire speedily, because the torque/inertia ratio of the output part is very high. The system provides high response and could be applied to the high speed operation such as sports training.

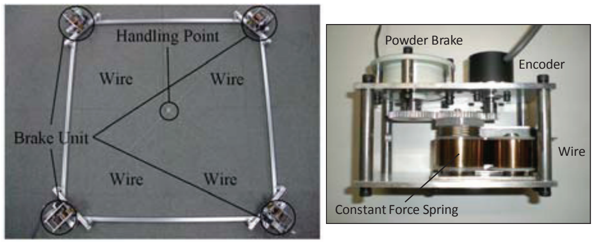


Fig.4 Passive Motion Support System

4.3 Path Following Control

By considering the problem of brake constraint, in this section, we propose a motion control method to guide the handling point. Firstly, we consider feasible braking forces. The brake constraint is determined by the position and direction of velocity of the handling point, that is, the feasible braking forces are depended on them. A set of vectors of the feasible braking force at a certain moment make a region in opposite direction of velocity of the handling point as shown in Fig.5. This region is a set of force vectors and call as the feasible braking force region.

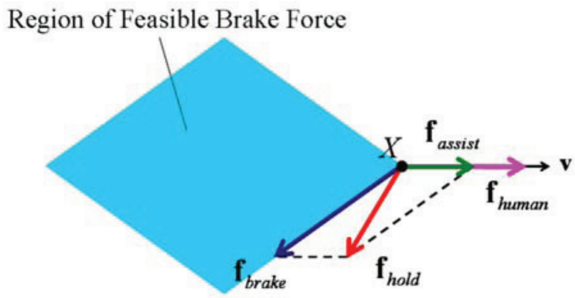


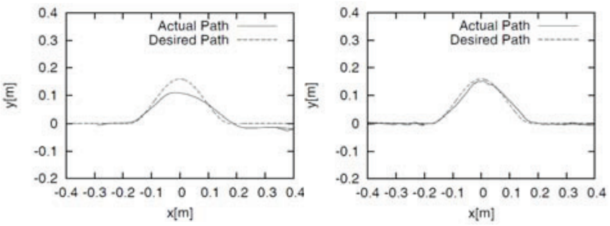
Fig.5 Region of Feasible Braking Force

We define a desired force to hold handling point on a path, when we realize a path following function. We assume that direction of human applied force and direction of velocity of the handling point are in the same direction, because inertia of the handling point is small. For an active type system using servo motors, we just simply command to servo motors of the system to generate torques for realizing this desired force. However, in the control of the passive system, the feasible braking forces always depend on the current motion of the system. If the desired force is within the feasible brake force set, we can command the braking force directly.

On the other hand, of course, many cases exist that the desired force is located out of the feasible set of the force as shown in Fig.5, and cannot be generated by servo brakes. When the desired force is located out of the feasible set of the force, we utilize a part of the human applied force to compensate the insufficient braking force. The force applied by the human could be divided into two elements. One is the driving force utilized for moving the handling point along the direction of the force applied by the human, and the other is the human assist force which compensates the insufficient braking force for realizing the desired force as shown in Fig.5. This means that the desired force could be generated by the composition of the feasible braking force and the assistive force, which is a part of the force applied by the human, even when the desired force is out of the feasible braking force region.

In this research, we prepared a cosine curve for the path following control experimentally. In this experiment, we did not show the desired paths explicitly on the experimental plane, and tell the user about only the kinds of following line such as straight line and cosine curve. The users conducted the experiments after several practices to follow the path.

The experimental results are illustrated in Fig.6. Fig.6(a) is the experimental result without support force in cosine curve following and Fig.6(b) is the experimental result with support force. The performance of path following is improved obviously.



(a) Without Control (b) With Control

Fig.6 Experimental Results for Curve Following

5 Concussions

In this article, we introduced a concept of passive robotics and proposed a new passive intelligent walker and a wire-type passive motion support system controlled by the servo brakes, to support the motion of the humans. Realizing the many functions of these systems is challenging, because we control only the servo brakes and use no servo motors. We proposed motion control algorithms considering the brake constraints and realized the several functions, which change the apparent dynamics of the passive systems to adapt to the states of the user and the environment.

In future work, we will consider the human adaptive and environmentally-adaptive motion control algorithms in more detail to improve the maneuverability of the passive systems. In addition, we will improve the mechanisms of them from the practical point of view.

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