Introduction to Mobile Robotics Lab.
(OTA Lab.)
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Service Engineering Research Division,
Research into Artifacts, Center for Engineering (RACE) 5F

The University of Tokyo
Kashiwanoha 5-1-5, Kashiwa, Chiba 277-8568, Japan
TEL:
Professor's room (509): +81-4-7136-4252
Laboratory (559, 561): +81-4-7136-4260
(534-A): +81-4-7136-4276
FAX: +81-4-7136-4242
URL: http://www.race.u-tokyo.ac.jp/otalab

Members

Professor	Jun OTA
Project Researcher	Lounell Bahoy GUETA
Doctoral Course Students	
	Yewguan SOO, Yusuke FUKAZAWA, Zhaojia LIU, Yanjiang HUANG
Master Course Students	
	Tian LI, Naoki OYAMA, Yoshihiro TAKEBE, Yuto NAKANISHI, Tadanobu MIZOGAKI, Hiroaki OGAWA, Yuusuke KARIYA, Yi-Heng KUNG, Theeraphol WATTANAVEKIN
Undergraduate Students	
	Hiromasa KAMOGAWA, Taizan YONETSUJI
Secretaries	
	Mari HIRATA Mika TAMURA

Research Topics of Mobile Robotics Lab. (OTA Lab.)

We have been studying multiple mobile robot systems since 1989. We consider intelligent systems as consisting of three factors: (a) multiple robots or intelligent machines (multiple agents), (b) human-beings who operate or cooperate with multiple agents, and (c) working environments. Now we deal with "multi-agent robotics and mobiligence", "design of large-scale production/transport systems", and "human analysis" based on motion planning methodology, evolutionally computation, control theory, and so on.

Our final target is to establish design methodology of multi-agent systems including artificial agents, humans and working environments through clarifying the function in intelligence and mobility (mobiligence) of these agents

Rearrangement Task by Multiple Mobile Robots

Rearrangement tasks involving multiple objects are fundamental for mobile robots. Robots transport objects from an initial configuration to a goal configuration. This type of task has various applications in production systems. These production systems needs to cope with various situations than a traditional AGV system because robots have to determine the order of transportation and moving paths autonomously. At first, robots develop their motion plans, and then realize these plans. It is unfeasible to apply traditional methods in a rearrangement problem due to multiple robots and movable object. The search space increases exponentially with the number of robots and objects. Furthermore, a real-world environment is quite complex and is very different from a simulation. To realize a rearrangement plan, we must deal with these differences. To solve the rearrangement problem and generate motion plan, we divide the entire complicated problem into two sub-problems: Project Scheduling Problem (PSP) and path planning problem for single mobile robot1). The PSP and path planning problem for a single robot have been studied previously. To architect a more compatible rearrangement plan applicable to various working environment, we proposed a task allocation method2). To cope with the difference between a real-world environment and a simulation, we divide developed plan into several “behavior”. Each behavior is designed to deal with some specific differences in achieving each sub-goal.

Keywords: Multiple mobile robots, rearrangement task, environmental model.

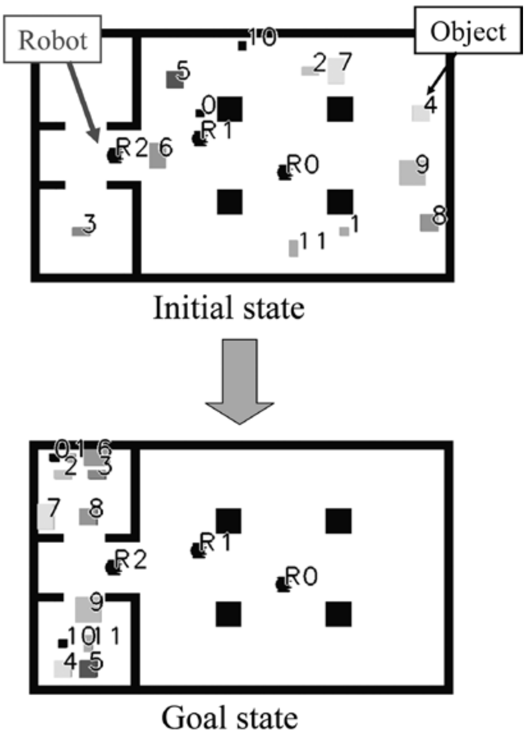

Fig.1 An example of a rearrangement task.

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1) Norisuke Fujii, Reiko Inoue, Yoshihiro Takebe and Jun Ota, Multiple Robot Rearrangement Planning Using a Territorial Approach and an Extended Project Scheduling Problem Solver, Advanced Robotics, 24, 1-2, p103-p122, 2010.
2) Naoki Oyama, Norisuke Fujii, Jun Ota, Rearrangement Task by Multi-Robot Group Using Robot Allocation Method to Divided Working Areas, Proc. SICE-SI2009, p2027-p2030, 2009. (*in Japan*)

Fig.2 A real-world environment.

Compact Design of a Redundant Manipulator System under a Task Completion Time Constraint

Ideally, manipulator systems must occupy minimal space to achieve a high density of work cells over a given area (spatial requirement) and be high-speed for high productivity (temporal requirement). Satisfying these two requirements is complicated due to conflicting constraints such as collision and motion time. In this study, a redundant manipulator system consisting of a 6-DOF manipulator and a 1-DOF rotating table is designed to be compact . A new *compactness* measure is proposed that considers the manipulator swept volume, which is crucial because the manipulator has a small footprint but can occupy a substantial space due to its large workspace (Fig.1). As a solution, a motion coordination based on the swept volume called spatial motion coordination (SMC) is proposed and is integrated with the base placement optimization and goal rearrangement (Fig. 2). In the proposed method, the task completion time is also minimized to a desired value, $t_{desired}$, to ensure that the system throughput is achieved. Therefore, SMC is evaluated under various $t_{desired}$ values and is compared with a motion coordination based on the task completion time called temporal motion coordination (TMC). The reduction in the system size is about 28% on the average by using the proposed method compared to a method using only goal rearrangement and motion coordination (Fig. 3). It is also found that the applicability of SMC and TMC depends on the $t_{desired}$ values (Fig. 4).

Keywords: Multiple-goal task realization, manipulator optimization.

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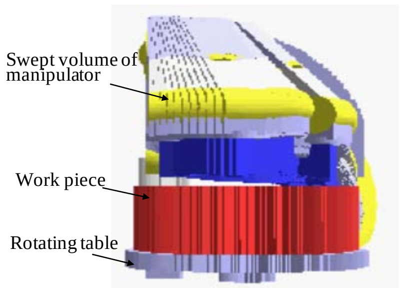

Fig. 1 Swept volume of a redundant manipulator system

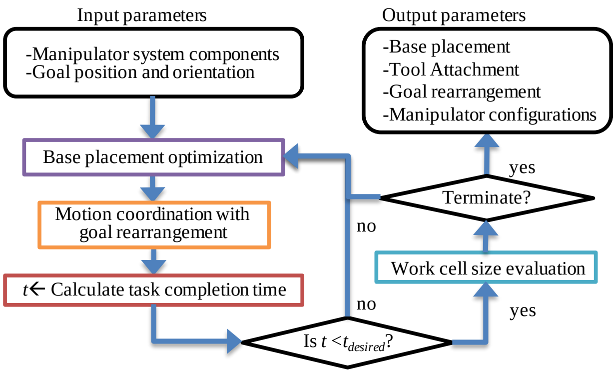

Fig. 2 Proposed method

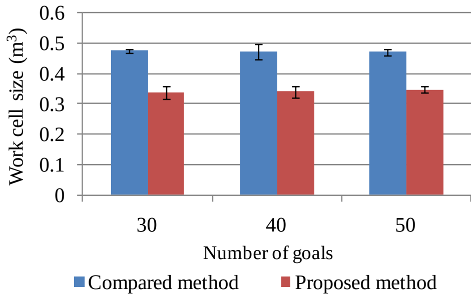

Fig. 3 Average work cell size derived by the compared and proposed methods.

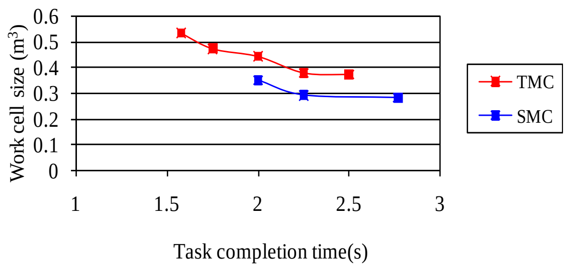

Fig. 4 Performance of SMC and TMC under various $t_{desired}$ settings

Control Methodology of Two Stacker Cranes in Automated Storage/Retrieval System

We propose control methodology of two stacker cranes to avoid collisions in an automated storage/retrieval system including the constraint on trajectories caused by dynamics as shown in Fig. 1. In the automated storage/retrieval system environment, there are three problems: constraint on trajectories caused by dynamics (e.g., vibration control), safety in the case of an emergency stop, and practical calculation time. In the proposed method, the motion is planned through two approaches. In the first approach, the trajectories of cranes are chosen from candidates that satisfy the constraint on dynamics and are checked to determine whether the selected trajectory ensures safety in case of an emergency. The calculation cost is reduced by confining the candidate trajectories using the characteristic of the number of cranes. If a collision cannot be avoided in the first approach, we adjust the confined candidate trajectories and find a suboptimal trajectory. The techniques used in the second approach are to delay the movement of cranes and to generate detours. Concretely, we set a via point on the line which is normal to the line between the current position of a crane and the collision point on the original trajectory, and the line is set to pass the collision point (Fig. 2). In the simulation, the working efficiency of the evaluated method is calculated as the ratio of the work time of a single crane to that of the method. The simulation results are shown in Table 1. The working efficiency is 1.98 when collision is ignored, 1.68 in a simple method, and 1.85 in the proposed method. If collision is ignored, the working efficiency is almost doubled compared to the case of a single crane. The results show the effectiveness of the proposed method.

Keywords: Motion Planning, Stacker Crane, Heuristics.

Reference

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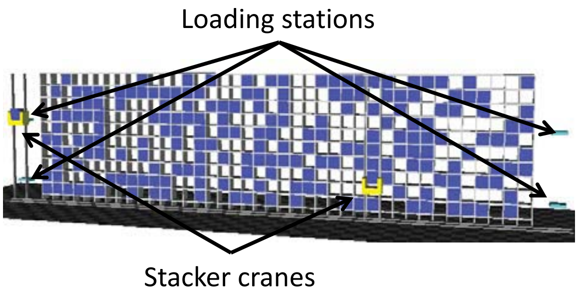

Fig. 1 An automated storage/retrieval system with two stacker cranes

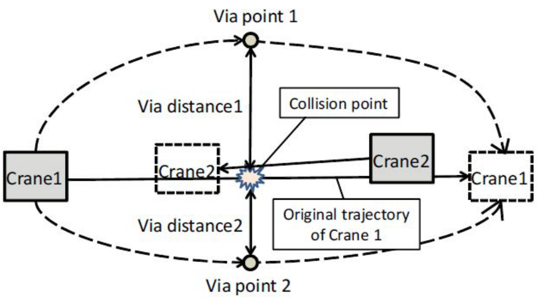

Fig.2 A technique to derive the via points

Table 1: Simulation results

	Work time (min.)	Working efficiency	Movement distance (km)	Waiting time (min.)
Single crane	15.49	1.0	2.43	0
Ignore collisions	7.83	1.98	1.25	0
Simple method	9.21	1.68	1.30	1.28
Proposed method	8.39	1.85	1.24	0.50

A Solution of the Asymmetric TSP with Time Windows

Travelling Salesman Problem (TSP) is a problem of finding a minimum travelling-cost route of n cities (Fig.1). Asymmetric TSP (ATSP) is a variant of TSP, where the travelling cost from city i to j is different from the one from j to i. TSP with time window (TSP-TW) is another variant of TSP in which a travelling time between two cities and a staying time for visiting each city are additionally defined and an allowed time-window for visiting each city is given as a constraint. These are combinatorial optimization problems, which are considered impossible to find optimal solutions in polynomial time.

This study deals with asymmetric TSP with time window (ATSP-TW). The formulation of ATSP-TW is shown in Fig. 2. An example of ATSP-TW is a slab sequencing problem in steel manufacturing. When rolling out a lot of slabs with various thicknesses and widths is conducted, the difference in thicknesses and widths of neighboring slabs causes the deterioration of product quality, which is reflected as the increase of production cost. Generally this cost is proportional to the differences of thicknesses or widths, but it is asymmetric; for example, the cost when rolling a wide slab after a narrow one is smaller than the cost in reverse order. Slab sequencing problem is a problem to determine the rolling order with minimal cost in consideration of the processing time and deadline of each slab.

Here, we aim to obtain a sub-optimal solution at the reasonable calculation time within five minutes for a large-scale ATSP-TW with up to approximately 300 cities. We are trying a method that relaxes the problem by adding the time-window constraint to the evaluation function and applies simulated annealing (SA), a kind of metaheuristics, for solving the problem.

Keywords : Time Window, Asymmetric TSP, Metaheurisitics.

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1) T.Mizogaki, M.Sugi, H.Nagai, M.Yamamoto, X.Wang and J.Ota, "A Solution of the Asymmetric Travelling Salesman Problem with Time-Windows Constraints," 22th SICE Symposium on Decentralized Autonomous Systems, pp. 315-320, 2010.

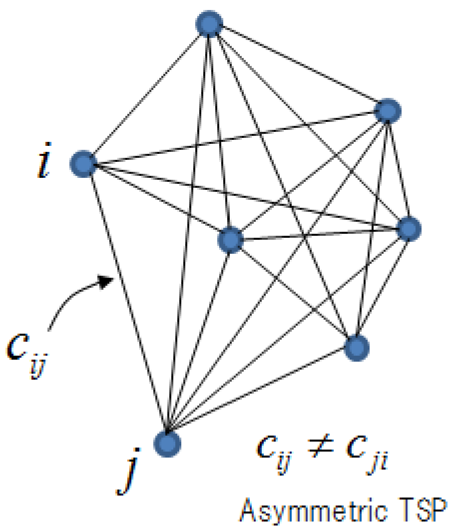


Fig.1 Graph expression of the TSP

$$\boxed{\text{Formulation}}$$

$$\min \sum_{i=1}^{n-1} c_{\rho(i)\rho(i+1)}$$

Subject to

$$V = \{1, 2, \ldots, n\}$$

$$\rho : V \to V$$

$$r_{\rho(i)} \le t_{\rho(i)} \le d_{\rho(i)} (i = 1, \ldots, n)$$

Fig.2 Formulation of the ATSP-TW

Basic Study for Modeling Human Posture Control

This study aims to clarify the mechanism of human posture control including the operation of the brain. We investigate the relationship of sensory input and muscular activity output for modeling. The human posture control is a very complex mechanism with multiple inputs and multiple outputs, because human, in order to move, controls several hundreds of muscular activities based on the information coming from the senses such as the sight, the sense of equilibrium and the somatic sense. Therefore, clarifying the control mechanism including the brain is very significant medically and biologically. It is necessary to construct the model because it is difficult to measure the operation of the brain directly.

We measure muscular activities in upright standing when the sight, the sense of equilibrium, and the somatic sense are obstructed or emphasized. Muscular activities are calculated using musculoskeletal simulator since using only electromyography (EMG) limits the number of measured muscles. Note that the muscles of the whole body are involved in the posture control. We calculate 94 muscular activities using musculoskeletal simulator. Specifically, we estimate non-measured muscular activities by inverse dynamics analysis from the musculoskeletal, ground reaction force, posture and measured EMG.

To verify the effectiveness of the proposed measurement, we experimented on the combinations of the sight obstruction (closed eyes), the sense of equilibrium obstruction (caloric test), and the somatic sense emphasis (contact from the outside) in upright standing. Figure 1 shows the result in the posture change (Fig.1). It is shown that a lot of muscles has activities significantly higher than other muscles not only when the posture is changed (when the sight and sense of equilibrium were obstructed as shown in Fig. 2(b) and Fig. 2(c), respectively) but also during a usual posture (when the sight and the sense of equilibrium were obstructed and the somatic sense was emphasized as shown in Fig. 2(d)). It is considered that these muscle activities are the results of the difference in the sensory input influencing the control system.

Keywords: Mobiligence, posture control model, musculoskeletal simulator, sense obstruction

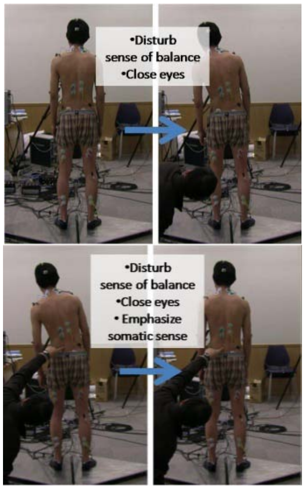
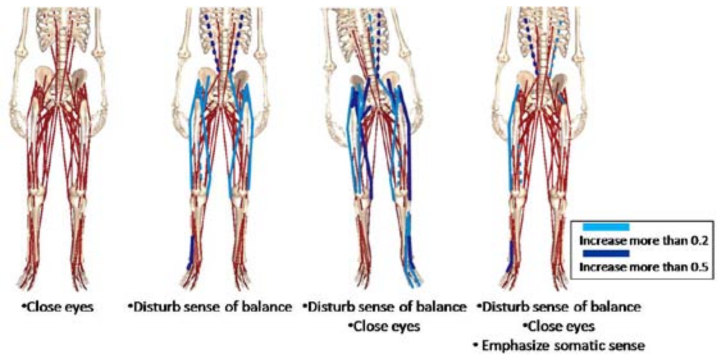


Fig.1 Postural changes under sensory input conditions



(a) (b) (c) (d)

Fig.2 Muscle activity compared with normal condition

Quantitative Estimation of Muscle Fatigue for Human Workers

Muscle fatigue is commonly associated with the musculoskeletal disorder problem, especially for those who perform monotonous or repetitive works such as assembly workers. This phenomenon has introduced the needs of monitoring the degree of muscle fatigue in the field of ergonomics and physiological research. Previously, various techniques have been proposed to index the muscle fatigue, however, quantitative measurement is still difficult to achieve. Muscle fatigue is a continuous process, which evolves over time depending on the effort exerted. The development of muscle fatigue will decrease the maximal muscle capacity to generate force. In this study, a fatigue model is constructed by assuming that the amount of muscle capacity lost is equivalent to the degree of muscle fatigue. A series of static contraction experiments (at 50% MVC) is conducted using a handgrip dynamometer to investigate the relationship between the handgrip work and the total force lost. This relationship is then modeled using an exponential fit as shown in Fig. 2. After that, the degree of muscle fatigue is estimated by calculating the handgrip work (which is the independent variable of the proposed fatigue model) from surface electromyography (SEMG) using the frequency-band technique [1]. The error of the estimated muscle fatigue from 10 subjects is shown in Fig. 3. The results show no significant difference ($p > 0.05$) between the estimated value from the SEMG signal and the one measured using a dynamometer. The fatigue model is only valid to the contraction level where it was calibrated. Similar procedures are required to reconstruct another model before it can be applied to different force levels.

Keywords: Surface electromyography (SEMG), muscle fatigue.

Reference

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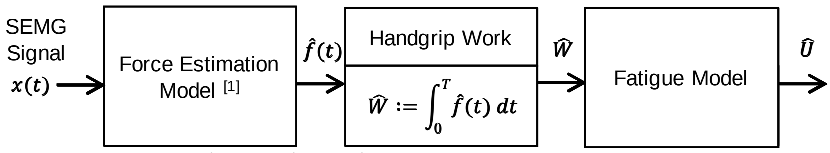

Fig. 1. Process for estimating the degree of muscle fatigue from the SEMG signal. The model has to be calibrated for each subject.

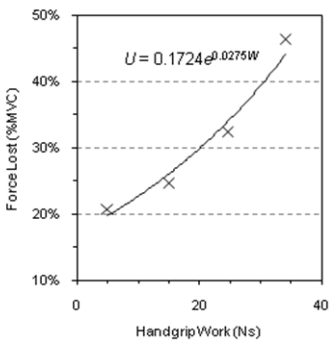

Fig. 2. An example of a fatigue model for one subject, which represents the relationship between the force exerted and the handgrip work.

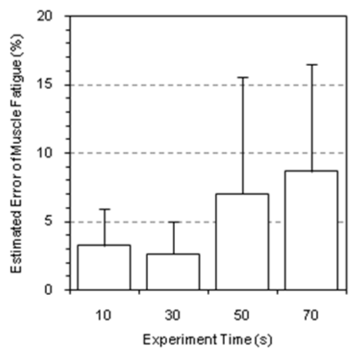

Fig. 3. Mean and standard deviation from 10 subjects, compared between the degrees of muscle fatigue estimated from the SEMG signal and the actual value measured using a dynamometer.

Inpatient Nursing Task Support

Nursing is characterized as a cycle management of patient conditions within the PDCA (Plan Do Check Action) conceptual framework. Due to *(i)* shortage of nurses and *(ii)* improving complexity of cares, nursing is regarded as one of the most challenging professions in Japan. Therefore, an effective nursing induction system for high-quality care is practically mandatory. The low level of staffing leads to higher level of patient mortality, which is partially due to the applied action rules of nurses. In order to improve this condition, we proposed a new analysis method to quantitatively elucidate the action rules of nurses on providing nursing care and a support system for nursing students to facilitate training in nursing activity order (Fig. 1).

To derive an efficient nursing activity order, we propose an effective scheduling method for nursing care scheduling problems based on the simulated annealing algorithm[1]. In the support system, sensor data are used to recognize nurse activities and determine the order of these activities. We attached four accelerometers (Fig. 2) to a nurse, calculated features and applied an SVM (support vector machine) classification algorithm. Through the experiments in simulated nursing conditions with 13 nursing activities, we evaluated the accuracy (Fig. 3) and had proven the effectiveness of the activity recognition for nursing care.

Keywords: Nursing care, action rule, scheduling, pattern recognition

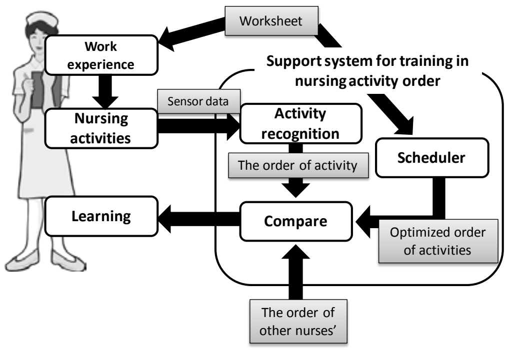

Fig.1 The support system for training in nursing activity order

References

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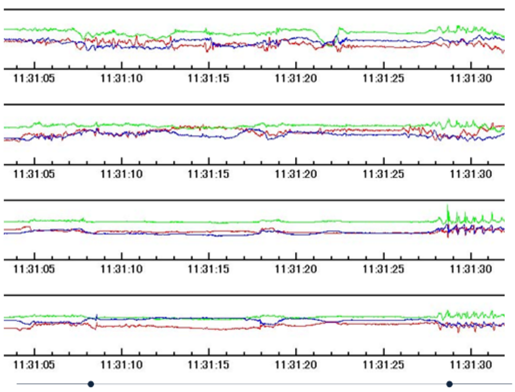

Fig.2 Accelerometer data

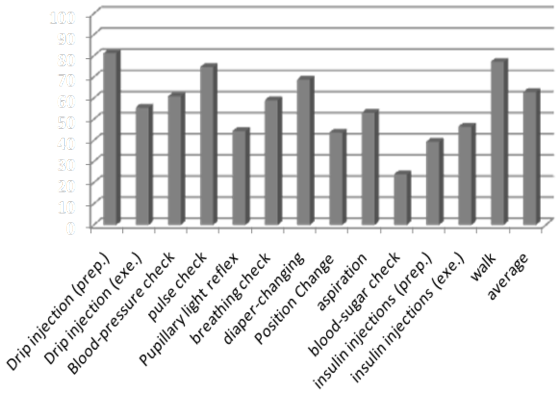

Fig.3 Accuracy of activity recognition

Attentive Workbench: An Intelligent Production Cell Supporting Human Workers

In recent years, manufacturers are required to maintain wide variety of product lineups according to diversifying consumer trends. Instead of conventional manufacturing lines, cell production systems, in which a single human worker assembles each product from start to finish almost manually, have come into wide use. With negative and zero growth of the population, we will face a shortage of skilled workers, and hence a great difficulty in maintaining the cell production system. In this respect, together with researchers in The University of Tokyo, such as Prof. Takamasu in the Dept. of Precision Engineering and Lecturer Kotani in School of Frontier Science, we have proposed attentive workbench (AWB) that is a system that supports human workers in cell production from both informational and physical sides (Fig.1). AWB recognizes the intention or the condition of a worker through cameras and vital signs monitors, presents the information through projectors, and supplies assembling parts to the worker using self-moving trays. We have proved the effectiveness of the present system through subjective experiments using the implemented AWB system (Figs. 2, 3).

We have also applied AWB for supporting deskwork in home/office environments. Instead of highly static and repetitive tasks such as in manufacturing, desk workers in home/office handle highly diverse duties, e.g., computer operation, document reading and writing, and eating foods. Therefore key issues in home/office environments are intuitive interface between users and the system and estimation of user preferences or intentions, both of which we are currently studying.

Keywords: Cell production system, attentive workbench (AWB)

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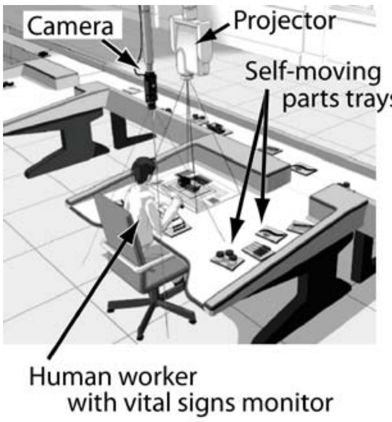

Fig. 1 Overview of Attentive Workbench

Fig. 2 Prototype model

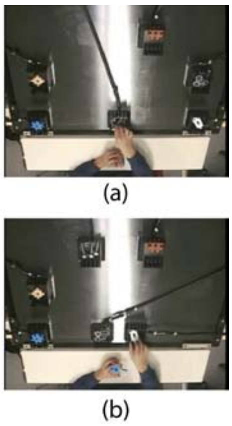

Fig. 3 Demonstration of physical assembly support

Automatic Modeling of User's Real World Activities and Its Application

The mobile Internet is expanding dramatically with the increase in the number of subscribers and the volume of mobile contents. As the mobile Internet gains popularity, information retrieval must be made easy and efficient. Thus, we investigate the automatic modeling of users' real world activities from the web. To estimate the hierarchical relationships present in the activity model with the lowest possible error rate, we propose a method that divides the representation of activities into a noun part and a verb part, and calculates the mutual information between them [1],[2]. The result shows that almost 80% of this relationships can be captured by the proposed method. Fig.1 shows a learned task-model. In our research, we incorporate this model into a content-based recommendation algorithm by representing both the content profile and user profile by a set of learned tasks [3]. From the user test, the obtained precision-recall curve is higher than that obtained by an existing content-based recommendation algorithm which uses noun-based features for both the content and user profiles. In addition, we incorporate the learned task into a map interface for mobile video navigation [4], allowing a user to find videos related to the activities around his current location (Fig. 2). The activities are expressed by pairs of sightseeing spot names and 3,300 kinds of verbs extracted from the Blog. A user’s evaluation test shows that the proposed interface increases the number of videos watched by about 3 contents compared to a video linked map interface by Google in a 40-minute test. In the area where a user has never visited, the number of videos watched increases twice showing the efficiency of the proposed interface to capture user interests in unknown places through mobile video navigation.

Keywords: Web mining, task model, recommendation, semantic search

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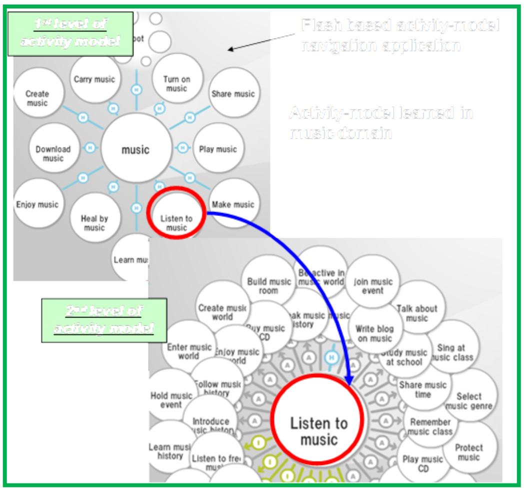

Fig.1 Learned activity model

Fig.2 TaskGuideRoid’s main screen image