Introduction to the Mobile Robotics Lab

(OTA Lab)

2025

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Research Topics (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 "design of robotics system", "design of large-scale production/transport systems", and "human analysis, service, and hyper-adaptability science" based on motion planning methodology, evolutionary 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 underlying structure and function in the intelligence and mobility (mobiligence) of these agents.

Current Research Topics

Multi-agent system and robot system design

- The acceleration of search in motion planning considering the dynamic characteristics of swarm AGVs
- Proposal of a General-purpose Algorithm of Split Delivery Vehicle Routing Problems for Multiple Agricultural Machines
- Robot System Arrangement Using Experience-based Hierarchical Optimization Methods
- Stepwise Large-Scale Multi-Agent Task Planning Using Neighborhood Search
- Visual-based Joint Compliance Calibration Using Measurement Pose Optimization

Human support robot system, human demonstration-based robot system, and manufacturing system design

- Dual-arm Demonstration Based Single-arm Robot Motion Planning for Pick and Place Task
- Learning Difficult Robot Motion from Human Demonstration Collected via a Single RGB Camera
- Fast and Flexible Optimal Motion Planning Algorithm Using Unreliable Human Demonstration Data
- Automatic Action Recognition Algorithm for Industrial Manual Worker with Human Skeleton and Object Information
- Learning from Human Hand Demonstration for Wire Harness Grasping
- Development of a Nursing Skill Training System Based on Manipulator Variable Admittance Control
- Multisensory Virtual Reality for the Analysis of Expert Inspection Skills
- A Knowledge-based System to Support Failure Cause Identification in Automated Manufacturing Lines
- Description Method and Failure Ontology for Utilizing Maintenance Logs with FMEA in Failure Cause Inference of Manufacturing Systems

Human analysis and embodied-brain system science

- Development of a Soft-type Glove Capable of Customizing Finger Rehabilitation Exercises Considering Differences in Physique
- Gait Analysis Using Machine Learning to Predicting Functional Independence
- Long Short-term Memory-based Gait Phase Prediction Using Heel Acceleration in People with Gait Disorders
- Modeling the Mechanisms of Human Postural Control
- Relationship Between Control Parameters Representing Gait in Parkinson's Disease and Clinical Measures
- Understanding the Mechanisms of Postural Biofeedback Training

The acceleration of search in motion planning considering the dynamic characteristics of swarm AGVs

This study addresses the challenge of efficiently planning conflict-free paths for Automated Guided Vehicles (AGVs) in automated production and logistics environments, a task known as the Multi-Agent Path Finding (MAPF) problem. The conventional method [1], based on Conflict-based Search (CBS) [2], has been effective but struggles with long computation times, especially as the number of AGVs increases or in constrained spaces. To overcome these limitations, the study proposes integrating greedy search techniques and machine learning into the CBS framework, aiming for faster computation without sacrificing planning quality. Specifically, it replaces A* search with either a weighted version or a machine learning-enhanced version and substitutes best-first search with beam search. A novel machine learning model (Fig.1 left) predicts heuristic values for path planning, trained on simulation data from AGV operations. This approach demonstrated a reduction in computation time and the number of top expanded nodes, maintaining high-quality motion planning. Fig. 1 shows a comparison of the proposed method against traditional approaches, highlighting the efficiency gains and effectiveness of incorporating machine learning into AGV path planning within complex logistical settings. These improvements highlight the potential of machine learning to enhance the efficiency and effectiveness of AGV path planning in complex logistical settings [3].

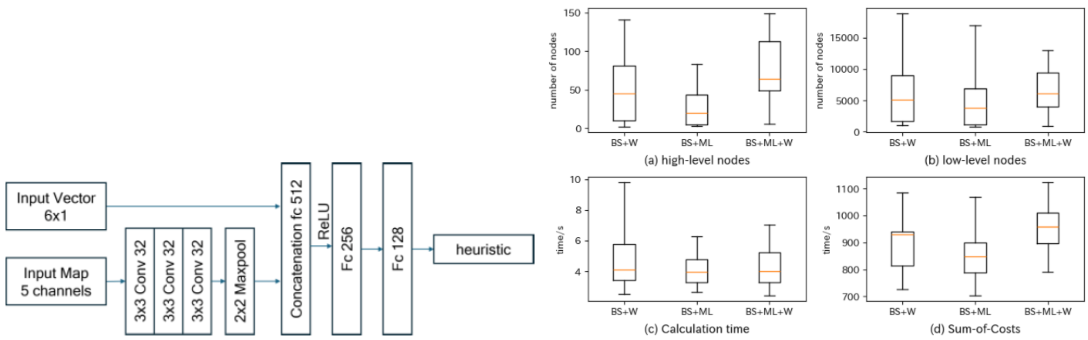

Fig. 1. Left: Proposed Model, Right: Simulation Results (BS: Beam Search, ML: Machine Learning, W: Weighted A* Search)

Keywords: Automated Guided Vehicle, Motion Planning, Multi-Agent Path Finding

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Proposal of a General-purpose Algorithm of Split Delivery Vehicle Routing Problems for Multiple Agricultural Machines

In recent years, there has been growing attention towards smart agriculture to enhance the efficiency of agriculture[1]. Farmers utilize multiple agricultural machines to work on several fields. In this process, it is necessary to decide (a) the assignment of tasks to agricultural machines for each field, and (b) the touring route of each agricultural machine for the fields they are responsible for.

Although various methods have been proposed in previous studies to address this problem, it is not clear which method is appropriate when conditions are specified according to the individual situation of a farm, leading to a lack of versatility in the dispatch system. Furthermore, in each method, hyperparameters (parameters set from outside that affect the algorithm's operation or performance) are empirically given, making it difficult to say that the full potential of each method has been utilized. For these reasons, the development of a versatile task allocation system has not been achieved. Therefore, this study aimed to develop a general-purpose task allocation system for agriculture [2].

In order to reach this objective, we developed a versatile task allocation system and verified its effectiveness. The results of the simulation are shown in Table 1. It was demonstrated that the simulated annealing method performs well for small agricultural field scales, while local search methods are superior for large scales with short calculation times, and the values of hyperparameters suitable for the scale of the agricultural field were derived. Going forward, experiments will be conducted targeting more agricultural field conditions and metaheuristics to further develop a versatile agricultural task allocation system, including the extraction of features necessary for selecting the appropriate algorithm.

Table 1. Best optimization methods and hyperparameter combinations according to farmland size and maximum calculation time

Farmland size	Max calculation time (sec): 1	10	100	1000
large	Local search	Local search	Local search	SA (Initial temperature, Cooling rate) =(25, 0.999)
medium	ACO (Evaporation rate, Initial pheromone, Secreted pheromone) =(0.9, 10, 0.1) etc.	SA (Initial temperature, Cooling rate) =(25, 0.99999)	SA (Initial temperature, Cooling rate) =(25, 0.9999)	SA (Initial temperature, Cooling rate) =(25, 0.999)
small	SA (Initial temperature, Cooling rate) =(25, 0.999)	SA (Initial temperature, Cooling rate) =(50, 0.9999)	SA (Initial temperature, Cooling rate) =(25, 0.99999)	SA (Initial temperature, Cooling rate) =(25, 0.999)

Keywords: Smart agricalture,   Multi-agent system, Split delivery vehicle routing problem, metaheuristic

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Robot System Arrangement Using Experience-based Hierarchical Optimization Methods

Industrial robots perform various tasks such as welding, assembling, spraying, and transportation in practical industrial environment. Although the motion planning or motion planning of the industrial robots are mostly focused on to improve the working efficiency, it is also highly influenced by the arrangement of the robot environment components, such as the base, conveyors, sensors, objects, and robots, during the execution of these tasks. Moreover, if the environment of a robotic system changes, the robot's motion must also change, even if it performs the same task, leading to significant changes in its tact time or energy efficiency. Therefore, the location and arrangement of the robotic environment significantly impact industry efficiency, and to enhance the productivity of a robotic system, it is crucial to have a proper setup of the robot system environment, along with planning effective robot movements.

However, most of conventional studies focused on the motion planning or path planning among those two aspects, hence, there is few studies which developed the algorithm to identify both optimal motion and environment arrangements. Therefore, this study proposed the new optimization methods for industrial robotic system which can facilitate both robot motion and environment arrangements' optimization[1]. Specifically, to address the difficulty of combined optimization problem of motion planning and environment arrangement, we used hierarchical algorithm [2] and experience-based method [3-4]. The former is to decompose the complicated problem into more simple ones to reduce the calculation cost, and the latter is to reuse the past solutions in similar optimization problem to find optimal solution faster, and we introduced two experience-based method for both motion planning and environment arrangement part.

To verify the effectiveness of the proposed method, we conducted the simulation experiment with a pick and place robotic system (Figure 1). In the experiment, the optimal robot motion from pick position to the place position, and positions of conveyors are calculated and compared with conventional techniques. Figure 2 shows the results of the experiment. As shown in Figure 2, we can solve combined optimization problem faster than conventional methods though our proposed method (left plot in Figure 2). Based on the results of this study, we will add further improvements on the proposed method.

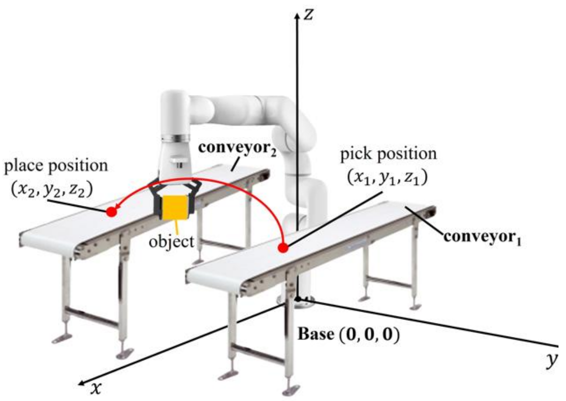

Figure 1. Schematic image of the typical pick and place robotic system.

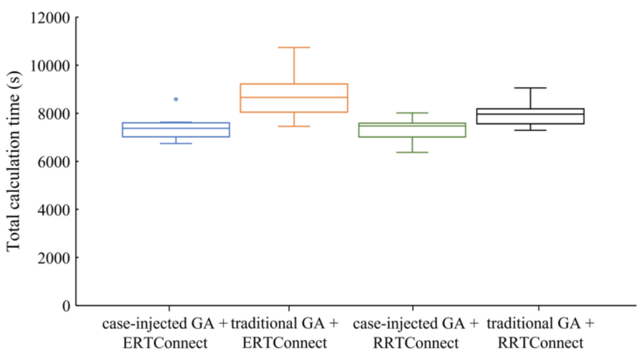

Figure 2. Boxplot of path length of four combinations of method.

Keywords: Robot motion planning, Environment arrangement, Experience-based optimization

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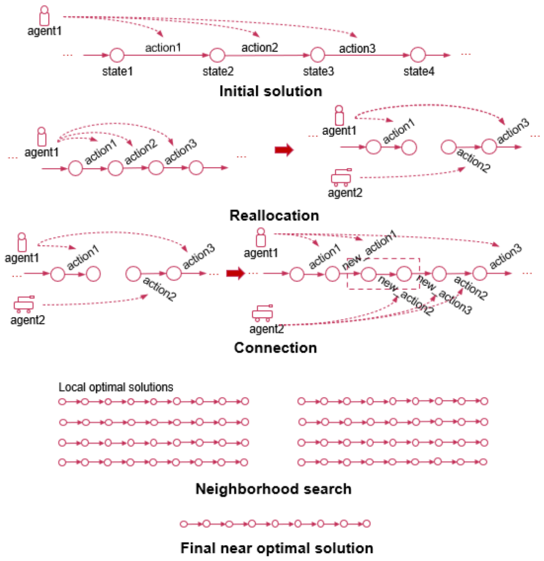
Stepwise Large-Scale Multi-Agent Task Planning Using Neighborhood Search

Multi-agent task planning aims to obtain a solution that can achieve goals using a group of agents by maximizing the overall performance of a system. This is a fundamental problem common in various fields, including robotics, transportation, logistics, and manufacturing. In terms of domain description, the STRIPS-style language [1] is often utilized because it allows the world to be described using predicates, which are statements that can be either true or false. Although this language facilitates scaling up to solve highly complex problems by adding more states and actions, the search space for finding solutions grows exponentially with the number of predicates. Such planning problems are PSPACE-complete and more difficult to solve compared to the NP-complete problems [2]. We present a stepwise method for solving multi-agent task planning problems in large-scale STRIPS-style problems described by the Planning Domain Definition Language (PDDL) within a realistic time frame. While existing planners [3] can promptly solve problems containing only a small number of agents, addressing large-scale problems efficiently remains a challenge. Our method [4] solves this problem by initially achieving the goals of the given problem using a minimum number of agents and then iteratively refines the solution through reordering and partially reallocating actions to other agents. During the local refining process, the reordering and reallocating may disrupt the original logical connections between adjacent actions, so our proposed method reconnects them by searching for optimal connections using a plangraph. The time complexity of obtaining a new solution using the connection of adjacent actions is linearly related to the length of the solution, which reduces the complexity to a polynomial level. The pursuit of realizing an optimal solution is abandoned since developing scalable and quick algorithms to realize optimality is not plausible. The refining process adopts a neighborhood search approach, treating reallocated and reordered solutions as neighbors. Additionally, tabu search is employed to iteratively escape the local optimal solution and ultimately obtain a near-optimal solution. What's more, we further extended this method to practical factory scenarios and considered human fatigue as an additional optimization criterion [5].



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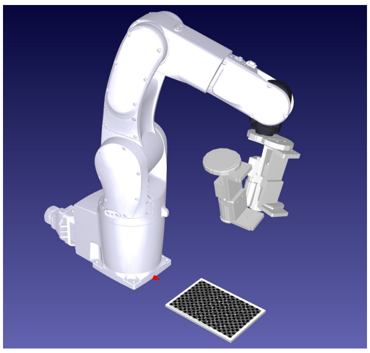
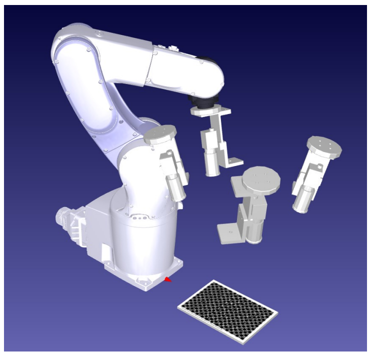
Visual-based Joint Compliance Calibration Using Measurement Pose Optimization

Robotic manipulators' motion accuracy can be affected by several factors, such as manufacturing tolerance, set-up errors, and wear and tear. While online teaching can ensure that manipulators coincide with the desired and actual motions, it can be a lengthy and resource-intensive procedure. Offline teaching with robot calibration can reduce the cost of online teaching, but joint offset calibration is essential for accurate motion. Several calibration methods have been proposed, including using specialized equipment to constrain the end-effector or tracking a laser pointer. However, joint angle offsets can account for up to 90% of the RMS value of the error, and joint offsets often change with daily use, making calibration an ongoing challenge.

To address this challenge, researchers have proposed using a single camera and a marker on the ground for calibration. However, the accuracy of pose estimation using this method is lower than laser tracking because of physical constraints. In this study, we propose a new method for determining optimal measurement poses using a hand-eye camera and a marker. Based on the previous observability index O1[1], we proposed an new index Ov1 to evaluate the effect of the error in the pose estimation based on the camera images on the joint compliance calibration[2]. The joint compliance calibration with the marker measurement at the poses, which obtained the optimization to maximize the proposed index, realized higher accuracy than other approaches.



(a) Optimized poses by O1



(b) Optimized poses by Ov1

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Dual-arm demonstration based single-arm robot motion planning for pick and place task

Demonstration-based learning has achieved great success in the area of robot motion planning [1]. In this process, a human demonstrator shows the ideal motions to the robot, and the robot tries to reproduce it. In general, the human demonstrator can only use the single hand to show the demonstration to the single arm robot even for the task where the human usually uses bi-manual hands (e.g., [2]). This is because the differences in the structure of the human and the single-arm robots. However, these "unnatural" demonstration may decrease the effectiveness of the demonstrations.

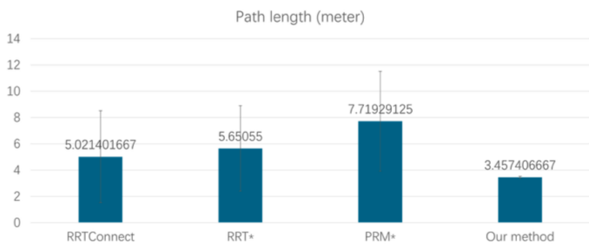
Therefore, on the basis of the above background, this study developed new demonstration-based motion planning algorithm which can facilitate the plan of the single arm robot using dual arm demonstration of humans. Figure 1 shows the target task of this study. In the process of the proposed algorithm, it first identifies the points that the human's both hands in the closest position. This point represents the change of the hand to be an effector to add the force to the target object. Then, the motions of both hands before and after this point are connected and generated the entire trajectory. Because the trajectory discretely "jumps" in the connection point, the low-pass filter was applied to smooth the data. Finally, the obtained trajectory information in the 3-dimensional space was converted to the robot motion in the configuration space by solving the inverse kinematic function. Through these processes, a single arm robot can learn how to solve the planning problem from a human's bimanual demonstration.

To verify the effectiveness of the proposed method, we conducted the experiment. In the experiment, the motion of the robot in the task shown in Figure 1 was evaluated and compared with some existing algorithms. The experiment results revealed that the proposed algorithm can solve the planning problem with higher success rate than the existing algorithms (Figure 2 (a)), and also increase the quality of the solution path (Figure 2 (b)). Based on the results of this study, we will add further improvements on the proposed algorithm, and verify the effectiveness of it in the more realistic situations.

Keywords: Motion planning, Learning from human demonstration, Bimanual motion

Figure 1. The target task of this study.

(a) Success rate



(b) Path length

Figure2. The results of the experiment. (a) Success rate, (b)Path length.

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Learning difficult robot motion from human demonstration collected via a single RGB camera

Demonstration-based learning has achieved great success in the area of robot motion planning. In this process, a human demonstrator shows ideal motions in the target task using some demonstration techniques, such as kinesthetic teaching, in which human operators directly contact and move the robot end-effector [1], or teleoperation, in which human operators indirectly move the robot through the controller and some other devices [2].

In this study, we propose a new demonstration-based motion planning method that can facilitate difficult motion planning problems in cluttered environments by using only human motion data collected via a single RGB camera as demonstration data [3]. Since existing methodologies in this research area require expertise in robot systems or robot motion planning, using such a simple measurement system (a single RGB camera) to facilitate robot motion planning is worthwhile from the viewpoint of the practical application.

Figure 1 shows an overview of the proposed method. As shown in Figure 1, the human demonstrator first shows the ideal motion in the target task in front of the RGB camera, and the motion is recorded as image data (Figure 1(a)). Then, the three-dimensional human skeleton information is extracted from the recorded image using skeleton recognition software, which serves as the demonstration data for robot motion planning. The extracted skeleton data is converted to the robot motion through the optimization process and saved as the motion template (Figure 1(b)-(e)), and then used as the demonstration data for solving difficult motion planning problems as shown in Figure 1(f). The point of this approach is that the extracted human skeleton data includes a large amount of noise, which decreases the reliability of the demonstration data. Hence, it cannot be directly used as the "strict solution" of the robot motion planning problem. To address this issue, we specifically introduce the path modification and adaptation process to fit the primitive robot motion generated from unreliable human demonstration data to the new environment. The results of simulation experiments showed that our proposed method can solve difficult motion planning problems significantly faster and with a higher success rate than the state-of-the-art motion planner.

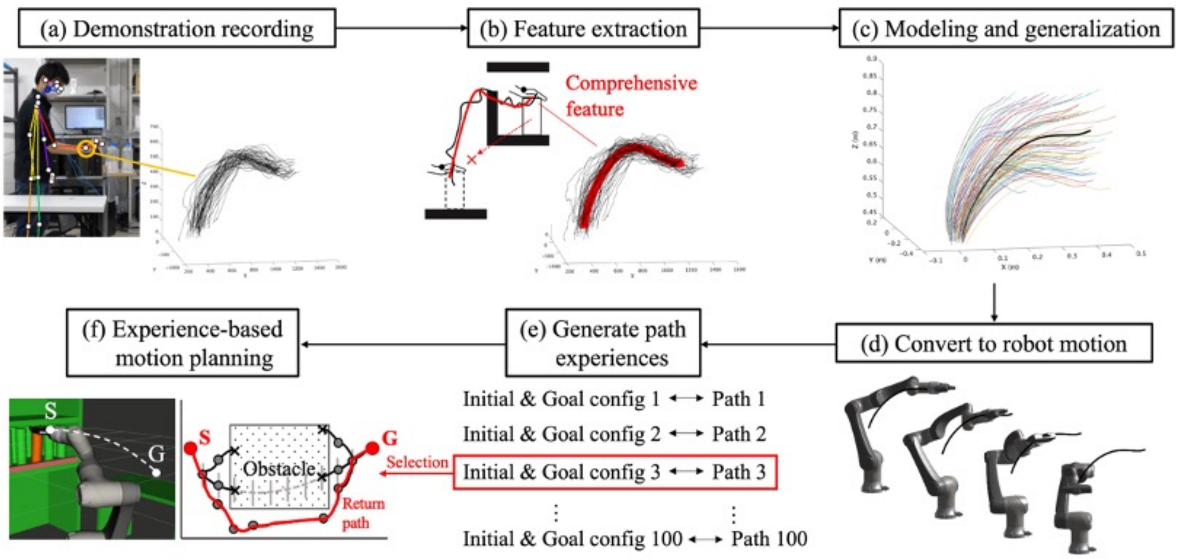

Figure 1. Overview of the proposed method. (a) Recording human motions and skeleton extraction, (b) Feature extraction from noisy human motion data, (c) Modeling extracted features, (d) Convert to robot motion, (e) Motion database development, (f) Motion planning based on the developed database./

Keywords: Learning from Demonstration (LfD), Motion Planning, Skeleton Recognition

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Fast and flexible optimal motion planning algorithm using unreliable human demonstration data

Demonstration-based learning has achieved great success in the area of robot motion planning. In this process, a human demonstrator shows ideal motions in the target task using some demonstration techniques, such as kinesthetic teaching, in which human operators directly contact and move the robot end-effector [1], or teleoperation, in which human operators indirectly move the robot through the controller and some other devices [2]. By using the human demonstration data, the robot can solve the difficult motion planning problem fast. However, the problem of existing studies is the dependency on the accuracy of the original demonstration data. If the accuracy of the demonstration data decreases, the performance of the existing demonstration-based planner also decreases. Although our previous work [3] partially solved this problem, it does not ensure the optimal motion to minimalize the path cost in the configuration space (C-space).

Based on the above background, this study developed new motion planning algorithm that can solve the optimal motion planning problem using the unreliable human demonstration data collected by a single RGB camera [3]. Figure 1 shows the overview of the proposed method. The algorithm first divides the demonstrated trajectory into several micro-pass, and flexibly explores the search tree in C-space. After finding an initial solution, it tries to reduce the path cost by rewiring the connection between previous sampling nodes. Through these processes, it can find an optimal path using unreliable human demonstration data.

To verify the effectiveness of the proposed algorithm, we conducted the experiment shown in the Figure 2. In the experiment, the motion of the human in two different tasks were collected by a single RGB camera, and used as the demonstration data. The experimental results showed that the proposed method can solve the difficult motion planning problems that cannot be solved by the standard motion planner more than 90 %, and reduce the path cost about 50%. Based on these experimental results, we will add further improvements on the proposed algorithm.

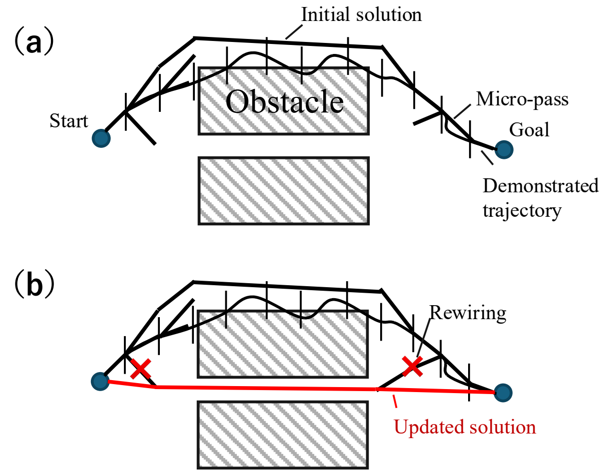

Figure 1. Overview of the proposed method. (a) flexible tree exploring using micro-pass (b) reducing path cost by rewiring.

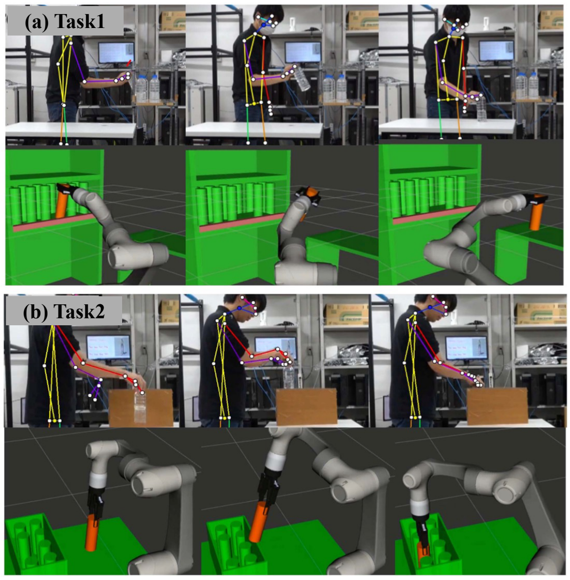

Figure 2. The experiment tasks, (a) pick-up objects from the shelf, (b) placing the bottle into the box.

Keywords: Learning from Demonstration (LfD), Optimal Motion Planning, Skeleton Recognition

References

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Automatic action recognition algorithm for industrial manual workers with human skeleton and object information

Time and motion studies, which involve dividing a worker's actions into several micro-actions, are a fundamental analytical technique in industrial engineering (IE). Through this analysis, we can identify wasteful parts of the worker's actions and make improvements based on it [1]. However, the problem with this approach is that it takes a large amount of time since it is usually performed by human analysts by hand. Therefore, to address this problem, we developed an automatic human action recognition (HAR) algorithm for industrial manual workers [2].

Although there are a huge number of studies that have tried to develop human action recognition algorithms [3], there are a relatively small number of studies that have dealt with human action in industrial situations. This is because, in the context of industrial manual workers, object and human-object interaction information must also be considered to recognize the worker's action. For example, although the action of reaching for an object and transporting an object are similar in terms of human kinematics, we can clearly discriminate between them in terms of the interaction of the objects. Therefore, to address these issues, we developed a specific algorithm which can deal with the human object interaction information.

Figure 1 shows the overview of the proposed algorithm's architecture. The input of the network is the image data of the human motion in the target task. This data is sent to both the skeleton recognition algorithm and object detection algorithm, and we get both human skeleton and object position (bounding box) information. Then, each data is input to the Bi-LSTM network, a type of machine learning technique for processing time series data, and the algorithm finally obtains an action label for each time sequence. Hence, by processing human motion information and object information, we can consider the interaction between the human and the objects.

To verify the effectiveness of the proposed algorithm, we conducted an experiment. In the experiment, we built the multiple regression model to predict the work delay of the worker in the various tasks such as pick-and-place or assembly and disassembly using the recognition results of the developed HAR algorithm. The results of the experiment revealed that the developed HAR algorithm can explain the variance of the work time by more than 50%. This result suggests the effectiveness of the developed algorithm to detect the cause of work delay and identify the points for the improvements. Based on the results of this study, we will add further improvements on the developed HAR algorithm and try to develop an automatic feedback system for the workers.

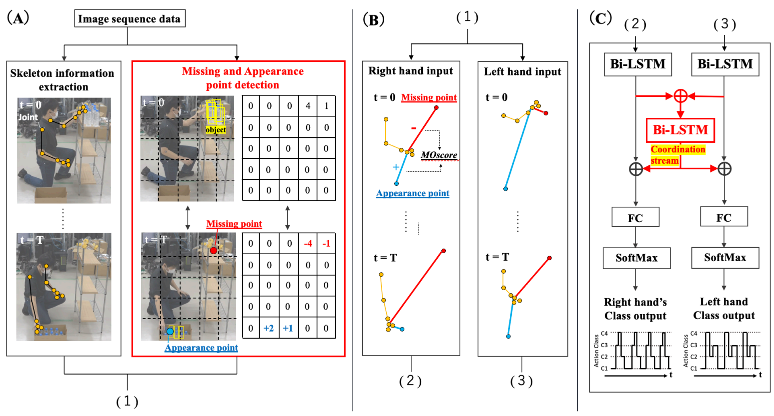

Figure 1. The developed HAR algorithm.

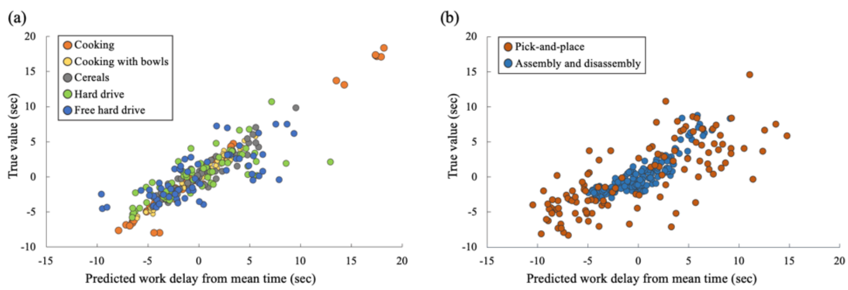

Figure 2. Prediction of the work delay using the developed HAR algorithm.

Keywords: Action Recognition, Object Detection, Industrial Engineering, Time and Motion Study.

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Learning from Human Hand Demonstration for Wire Harness Grasping

In recent years, the automation of bin picking in factory has made significant strides. The automation of rigid objects, such as metal components, has been successfully implemented by leveraging 3D data [1]. However, for deformable objects like wire harnesses, where the object's pose is uncertain, practical implementation is challenging. In most cases, manual intervention remains predominant.

To overcome this problem, we propose a system wherein human operators teach a robot wire harness grasping actions through hand demonstrations [2]. The process involves capturing human grasping of the wire harness and instructing the robot based on RGB-D images to learn the human grasped location and grasping posture. We notice that human tends to grasp specific regions with characteristic structures of wire harnesses. In order to learn such information, we propose a method to build a dataset for neural network training with few shot images. We form the problem as instance segmentation and augmentation of the training dataset is achieved by overlaying wire harness images onto various backgrounds.

Next, the obtained point cloud of grasping locations is aligned with the point cloud from the demonstration instances through point cloud registration. Using such information, the robot transfers the wire harness grasping pose during the demonstration to the current scenes.

We evaluated the accuracy of grasping location segmentation and the success rate of wire harness grasping in real experiments. Future work may include testing different types of wire harnesses, increasing the number of wire harnesses in the box, and dealing with targets near the corner.

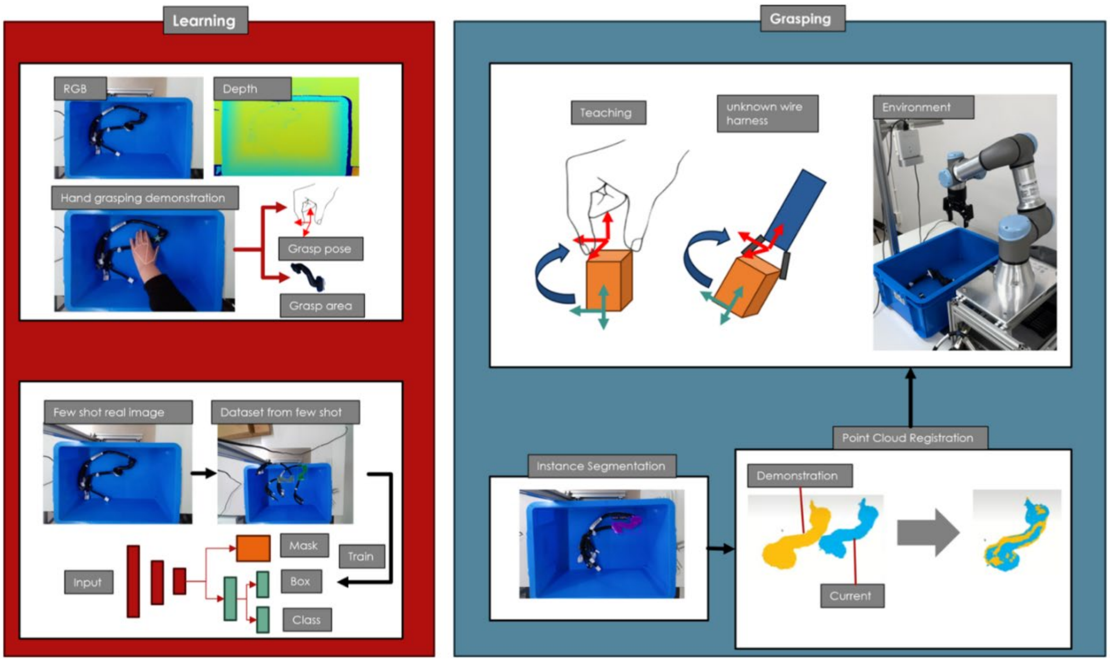

Fig 1.

Overview

Keywords: Grasping, Learn from demonstration, Wire harness detection

References

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Development of a Nursing Skill Training System Based on Manipulator Variable Admittance Control

Due to the recent aging society and shortage of nursing experts, the use of robot-based skill training systems is an emerging topic in nursing education, as many innovative robotic systems have been developed to simulate real patients, offering a safe and self-directed platform for nursing students to learn and practice their skills. Among these training systems, several human patient simulators (HPS) [1-3] have been proposed to simulate the patient's performance during patient transfer; however, without an entire motion model and control strategy, most HPS show limited effectiveness in simulating actual patient behavior.

Herein, this work presents a novel patient transfer training system that has the potential of improving the practical skills of nursing students [4]. The reason we set the patient transfer skill as the target of our system is that it is one of the highest risk motions which causes both patient and nurse's injury among many nursing skills, hence improving the novice's skill of patient transfer contributes to reduce the injury in the practical situation. The procedure of development our training system is as follows. First, we propose a simplified force model for patient transfer motion to estimate the contact force in the absence of wearable sensors (Figure 1). We then reveal the correlation between the nurse's force and patient's motion during the transfer through the utilization of the variable admittance model. Finally, we demonstrate the feasibility of the proposed patient transfer training system by performing several experiments on a UR10e robot. To the best of our knowledge, this system is the first patient transfer skills training system that simulates force interaction between nurse and patient using a collaborative robot.

Figure 2 shows the example of the training of the patient transfer motion with proposed training system. As shown in Figure 2, the patient can train and learn the transfer motion through the system. We anticipate that our proposed system will be an effective aid for student nurses to learn patient transfer skills. We believe that this innovative approach can make a contribution to the field of nursing education, addressing the current challenges of inadequate resources for nursing education.

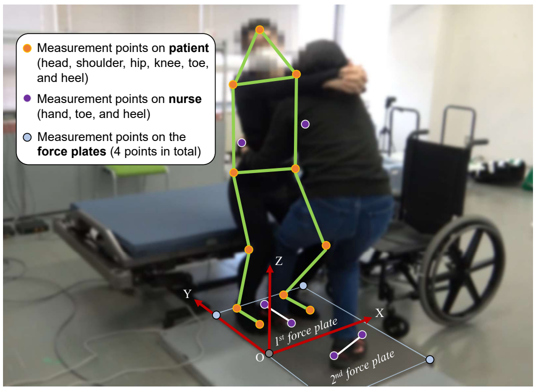

Figure 1. Modeling interaction between the patient and nurse.

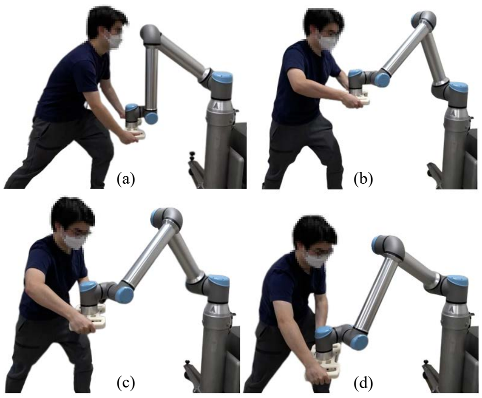

Figure 2. Example of the training with proposed system.

Keywords: Robot patient, Modeling of human motion, Nursing education

References

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Multisensory Virtual Reality for the Analysis of Expert Inspection Skills

Refinery inspection is the fundamental meintenace task that expert inspectors move around the vast reifinery area and try to find any defects or sign of it. Since even the slight defects will cause serious accidents in the real refinery, it owes a critical role for safety management. Therefore, to achive the more stable and safety refinery operation, it is important to investigate how expert inspectors can find such a small defects from a vast refinery area, and how different their inspection behavior from novice's one, namely, analysis of the expert inspection skill is a critical aspects for refinery safety management.

From the above background, in a previous work, a Virtual Realiry (VR) system is used to collect data of both experts and novices inspectors, and clarify the differences between them [1]. As a results, they revealed that expert inspectors tend to set their head in more effective position for finding the defects (e.g., lowerer position for leakage inspection). However, the problem of these previous studies is the lack of multimodality of the providided stimuli from the system. While the expert inspectors identify the multisensory information of the auditory, olfactory and haptic in addition to the visual information, the existing VR system can only provide the visual information. To deeply understand the expert skills in the refinery inspection task, we need to evaluate the inspection behavior under the provision of the multisensory information.

From the above back ground, this study newly developed multisensory virtual reality system that can provide four different sensory information of the visual, auditory, haptic and olfactory information simultaneously [2]. Figure 1 shows the overview of the developed system. In this system, the user tries to find a defect in the virtual refinery while using the multisensory information such as "see the bottom part of the pipe because the anoral vibration was detected. "

To verify the effectiveness of the developed system, we conducted the experiment. The 9 expert and 11 novice inspectors participated in the experiment. The experimental task is to find the anormalies randomly set on the virtual refineary within the 2 min. The results of the experiment revealed that (1) the expert inspectors showed the higher probability for the "multisensory anormalies" which require inspectors to use more than two different sensory stimuli for the detection (2) they tend to both gaze at and touch on a longer time with the important component such as a rotating machine. These results showed the effectiveness of our developed system to analyze the complex perceptual-motor behavior of the expert inspectors.

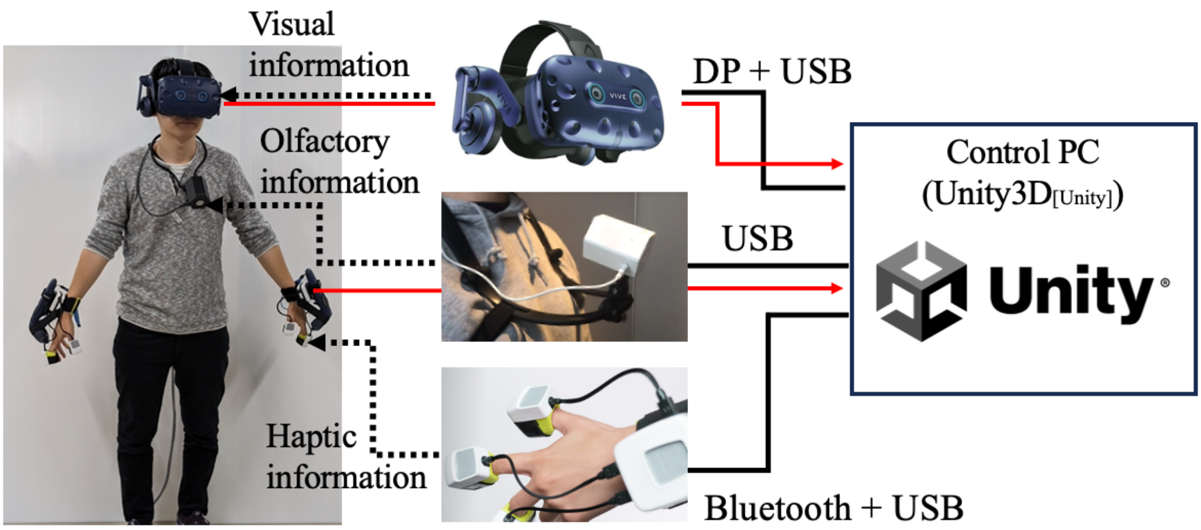

Fig 1. The multisensory virtual reality developed in this study.

Keywords: Expert Skills, Virtual Reality, Mulisensiry Information, Inspection

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A Knowledge-based System to Support Failure Cause Identification in Automated Manufacturing Lines

This research proposes a system to support the identification of failure causes in automated manufacturing lines. Maintenance activities in automated manufacturing lines require deep understanding of equipment and skilled techniques, making it effective to reuse knowledge from widely-used Failure Mode and Effect Analysis (FMEA). While previous studies developed systems that could retrieve failure causes from past FMEAs, knowledge reuse across different manufacturing lines remained challenging.

In this study, we construct a knowledge graph by extracting concepts from manufacturing lines (actions, states, parameters, and process components) from FMEA descriptions and representing relationships between these concepts. We then embed this graph using RGCN and use the resulting vector representations to infer failure causes. Experiments using FMEA data from automotive sensor assembly processes achieved accuracy comparable to benchmark methods when inferring causes for "substrate assembly position misalignment." This approach enables knowledge reuse across different manufacturing lines, promising more efficient failure cause identification.

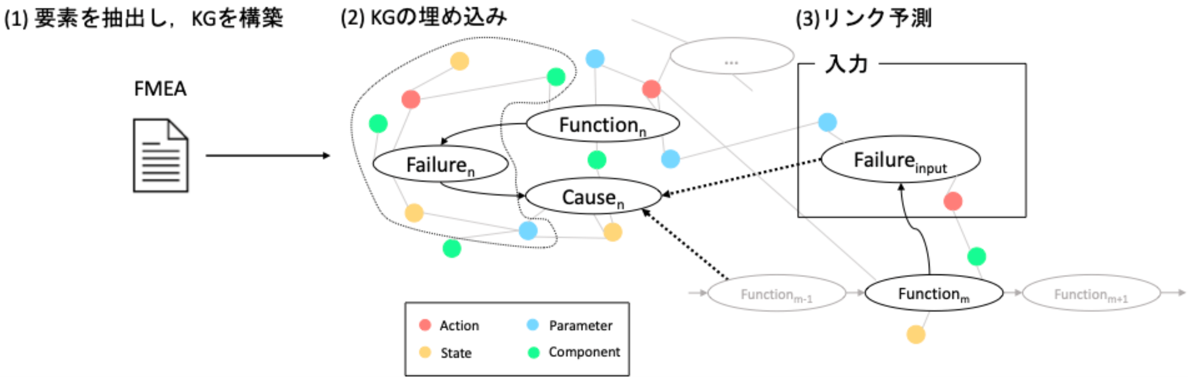

Fig. 1. Overview of the proposed framework.

Keywords: Manufacturing system, failure cause identification, FMEA, Maintenance log, Ontology

References

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Description Method and Failure Ontology for Utilizing Maintenance Logs with FMEA in Failure Cause Inference of Manufacturing Systems

In improvement activities aimed at maintaining and enhancing the production efficiency of manufacturing systems, investigating the causes of failures is crucial. However, this is a difficult task for non-experts who lack knowledge and experience. Consequently, various support methods leveraging past failure analyses conducted by experts have been explored. Thus far, FMEA (Failure Mode and Effect Analysis) has been widely used for failure cause inference. However, when using FMEA for failure cause inference, the results have shown a low degree of agreement with the candidate causes enumerated by experts for the same failure. This is because, when identifying failure causes, experts focus on more detailed aspects than those described in FMEA, suggesting the need to use maintenance logs that contain more detailed descriptions than FMEA in failure cause inference [1]. A notable characteristic of maintenance logs, which record actual maintenance activities, is that the quantity and format of the descriptions are not standardized. Furthermore, while FMEA is created by hierarchically analyzing the structure of the target system, making the hierarchy of described failures clear, maintenance logs provide no fixed hierarchy for describing failures and therefore tend to be inconsistent. For these reasons, current maintenance logs make it difficult to extract the causal relationships necessary for failure cause inference and are hard to reuse.

In this research, we propose a description method for recording maintenance logs in a highly reusable form, along with an ontology for organizing the described failures. Our goal is to improve the quality of failure cause inference for manufacturing systems by using maintenance logs in conjunction with FMEA. To this end, we propose a description method for maintenance logs that extends FMEA. We describe the causal relationships between failures and the relationships between failures and functions, and represent each description in both FMEA and maintenance logs as instances of a past-case ontology. Additionally, we constructed a failure ontology within a domain ontology, expressing failures in terms of the process of occurrence and the conditions impaired by each failure. To evaluate the proposed approach, we compared inference that uses both FMEA and maintenance logs with inference using only FMEA. We compared the inference outputs to the candidate causes enumerated by experts for the same failure, and evaluated them using two indices: Precision and Recall. The results, shown on the right side of Figure 1, demonstrate that the description method for maintenance logs and the failure ontology proposed in this study are effective in improving the quality of failure cause inference [2].

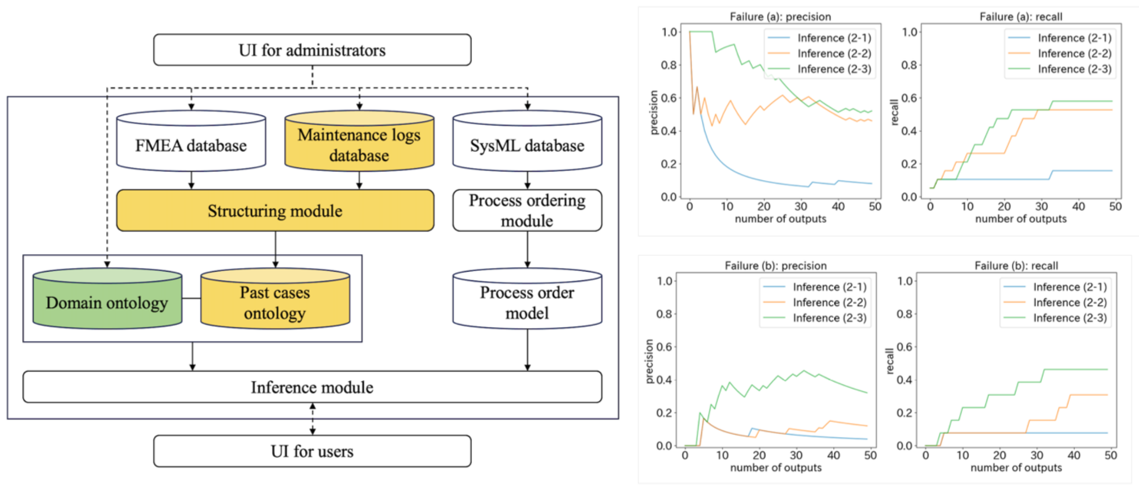

Fig1 Left: Overview of the proposed framework,
Right: Inference results (proposed method, blue: inference using only FMEA)

Keywords: Manufacturing system, failure cause identification, FMEA, Maintenance log, Ontology

References

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Development of a soft-type glove capable of customizing finger rehabilitation exercises considering differences in physique

When designing a hand rehabilitation device, it is important to account for the differences in physique among patients and tailor the rehabilitation exercises to each patient's needs. In this study, we present the soft cable-driven glove capable of easily adjusting the glove to fit the individual physique of the patient and customizing finger rehabilitation exercises. Considering the length of the phalanges and the thickness of the finger, the position of fixed parts on the index finger can be easily adjusted. In order to enable various index finger rehabilitation appropriate for the patient, four cable based cable routing for the index finger was adopted. The kinematic model of the glove was experimentally verified and utilized to plan the rehabilitation exercises. Based on this kinematic model, four representative finger rehabilitation exercises were operated with the developed glove on four different sizes of artificial fingers. The adaptability and adjustability of the glove to four artificial fingers were proved by demonstrating the possibility of assisting with various rehabilitation exercises while driving the three joints of the index finger independently. [1].

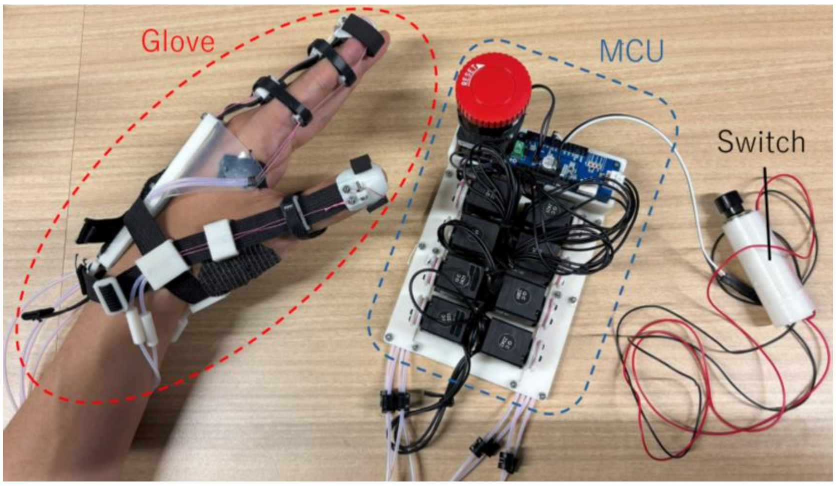

Fig 1 Glove and motor control unit

Keywords: Assistive device, Fingers, Rehabilitation, Kinematics, Engineering in medicine and biology

References:

[1] R. Nishizawa, T. Hasegawa, S. Shirafuji, J. Ota and A. Yozu, "Development of a soft-type glove capable of customizing finger rehabilitation exercises considering differences in physique*," *2024 46th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*, Orlando, FL, USA, 2024, pp. 1-4,

Gait Analysis Using Machine Learning to Predicting Functional Independence

Parkinson's disease is a neurodegenerative disease that occurs most frequently in the elderly, and the number of patients is increasing year by year. Gait disorder is a major factor in the decline of independence in daily living of patients with Parkinson's disease, and gait disorder is a major target for rehabilitation. However, it is unclear what specific gait parameters affect the improvement of patients' independence in daily living. In order to plan effective rehabilitation for patients with Parkinson's disease, it is instrumental to capture the detailed changes in gait and quantitatively analyze how these changes affect the patients' ability to live independently. In this study, we have been investigating what kinds of gait parameters change affect the level of independence in daily living by regularly measuring the gait of patients with Parkinson's disease. We showed that the degree of independence in daily living can be predicted from gait parameters using machine learning methods. In the future, based on the model used for prediction, we aim to clarify the specific gait parameters that contribute to the improvement of independence in daily living. [1].

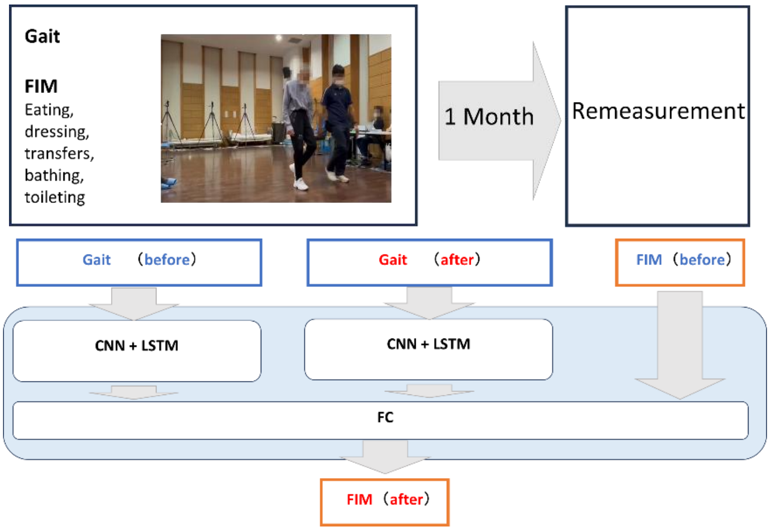

Fig 1 Measurement Procedures and Prediction Models

Keywords: Parkinson's disease, Gait, Independence in daily living, rehabilitation, machine learning

References:

[1] M. Ishikawa T. Hasegawa, K. Kaminishi, R. Chiba, J. Ota and A. Yozu, "Analysis of gait factors relevant to daily living in patients with Parkinson's disease, *2024 46th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*, Orlando, FL, USA, 2024.

Long short-term memory-based Gait Phase Prediction Using Heel Acceleration in People with Gait Disorders

Gait phase Prediction is essential for the proper and accurate control of gait-assistive orthoses. In this study, the gait of both healthy volunteers and people with gait disorders was measured by motion capture. A prediction model of gait phase was constructed using long short-term memory, a type of neural network. The heel acceleration data were used as input and the model predicted the gait phase 0.1 s ahead. To improve the prediction accuracy for patients, we propose a method in which a model is created for each individual participant and the length of the input acceleration data is adjusted according to the length of one gait cycle for that participant. The prediction accuracy of the gait phase was 84% using the conventional model and 89% using the individual model. This prediction model is expected to be applicable to gait-assistive orthoses [1].

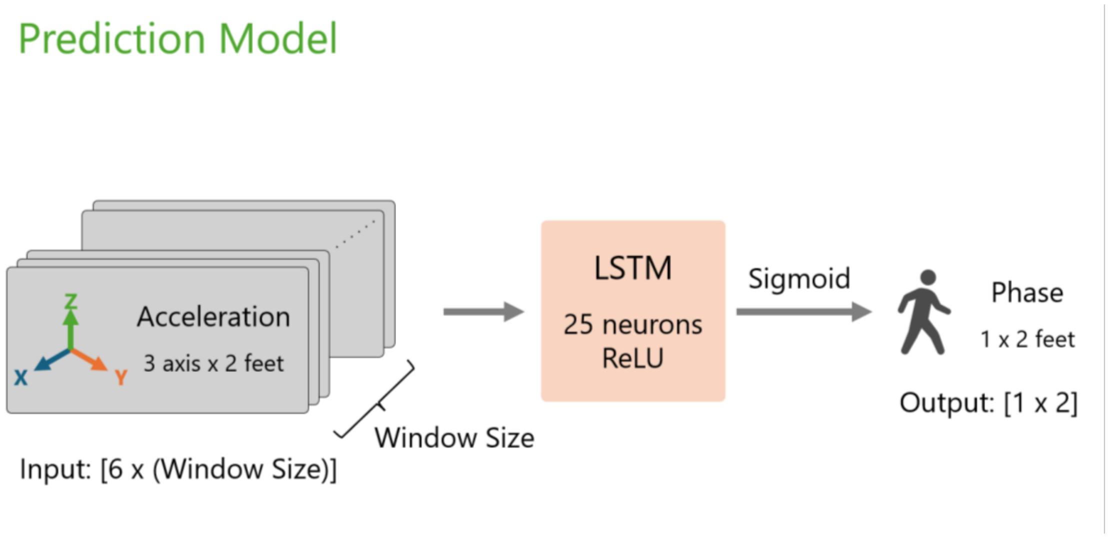

Fig 1. Prediction model of gait phase

Keywords: Gait Phase, Prediction, Gait Disorders, Deep learning, Long short-term memory

References:

[1] Y. Totoki, T. Hasegawa, S. Shirafuji, J. Ota and A. Yozu, "Long short-term memory-based Gait Phase Prediction Using Heel Acceleration in People with Gait Disorders," 2024 46th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), Orlando, FL, USA, 2024, pp. 1-4

Modeling the Mechanisms of Human Postural Control

A deep understanding of human postural control mechanisms is essential for developing effective rehabilitation strategies. One powerful approach to achieve this is to apply control models to physical body models and analyze their behavior through simulation. In our research, we aim to elucidate human postural control mechanisms by using musculoskeletal models that incorporate numerous muscles and joints, along with dynamic simulations.

Stepping in place is widely used as an important indicator for evaluating motor function in patients. While several control models have been proposed for simulating standing, walking, and other related tasks, there has been no control model capable of generating stepping movements. Therefore, we developed a novel control model for stepping, inspired by existing gait control models—particularly those based on muscle reflexes. As a result, we successfully reproduced stepping-in-place behavior using a musculoskeletal model. Moreover, by adjusting model parameters such as muscle weakness or increased muscle tone, we were able to replicate clinical observations such as reduced movement amplitude and slower movement speed.

In addition to stepping, we have also conducted musculoskeletal simulations of standing, walking, and the transitional movement of gait initiation. In particular, we are developing control models that incorporate the abnormal muscle tone often observed in patients with Parkinson's disease, aiming for future applications in rehabilitation support technologies and clinical interventions.

Fig 1. A neural controller model of standing postural control considering dopamine function.

Keywords: Postural Control, Musculoskeletal Model, Stepping

References

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Relationship Between Control Parameters Representing Gait in Parkinson's Disease and Clinical Measures

Parkinson's disease is a neurodegenerative disorder in which patients frequently exhibit gait impairments. Understanding how these impairments relate to commonly used clinical measures provides valuable insights for determining effective rehabilitation strategies.

We addressed this issue using musculoskeletal simulation. Specifically, we fitted a musculoskeletal model and a neural control model to gait data obtained from PD patients. We then analyzed the relationship between the resulting control parameters and clinical measures recorded for the same individuals. As a result, we identified subsets of control parameters that were correlated with specific clinical measures. These findings suggest that different motor impairments—quantified through clinical evaluations—may be characterized by distinct sets of control parameters. Furthermore, we formulated these relationships using a linear regression model and successfully estimated control parameters from clinical measures alone, allowing us to simulate patient-specific gait patterns through musculoskeletal simulation.

In the future, it may become possible to estimate or even predict gait impairments solely based on clinical measures. Conversely, it may also be feasible to infer the severity of motor impairments from observed gait patterns.

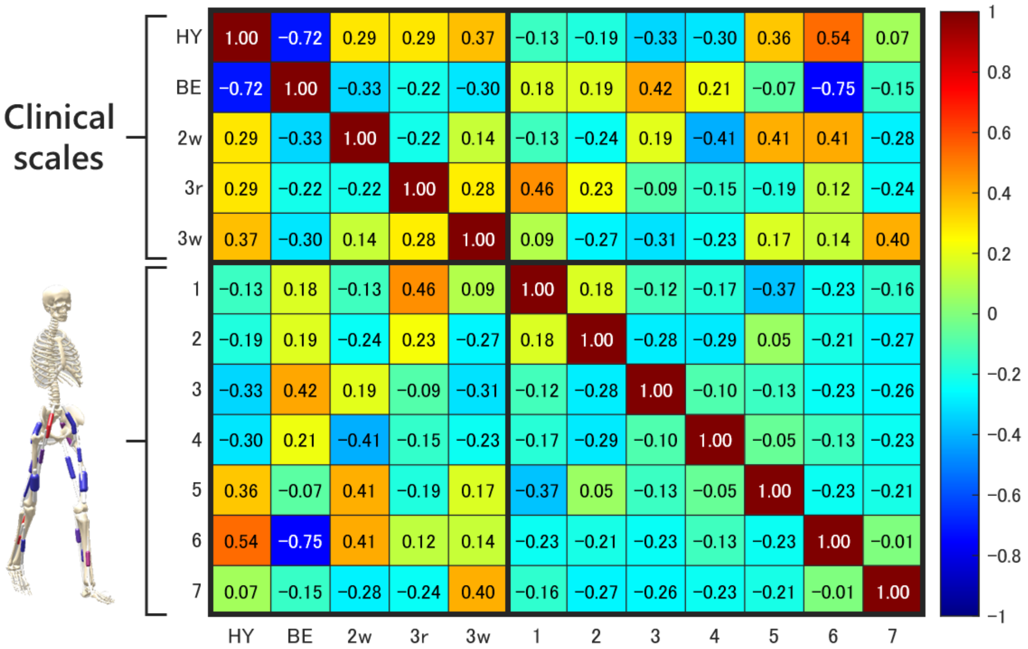

Fig 1. Correlations between clinical scores and dimensionally-reduced control parameters.

Keywords: Postural Control, Parkinson's Disease, Gait, Musculoskeletal Model

References

[1] Kaminishi, K., Chiba, R., Takakusaki, K., & Ota, J. (2024, November). Towards Data Augmentation for Parkinson's Disease Gait Data Using Neuromusculoskeletal Simulations. In *International Conference on NeuroRehabilitation* (pp. 208-212). Cham: Springer Nature Switzerland.

Understanding the Mechanisms of Postural Biofeedback Training

Postural biofeedback training, which provides individuals with real-time feedback on their posture, has been proposed as a method to compensate for balance impairments caused by aging or neurological disorders. Although the effectiveness of such training has been reported, the underlying mechanisms that lead to improvements in balance remain unclear. Our research aims to elucidate these mechanisms.

We conducted a longitudinal intervention in which participants received real-time feedback on their center of pressure (CoP), measured at the soles of their feet, over a defined training period. In addition, quiet standing tasks were performed under both eyes-open and eyes-closed conditions before and after the training. This experimental design allowed us to examine whether postural biofeedback training alters the integration or relative weighting of sensory modalities—such as visual, somatosensory, and vestibular inputs—which may in turn contribute to improved balance control. The results indicated a relationship between within-day changes in postural sway and changes in the utilization of sensory information. Furthermore, there was a possible difference in this relationship between the trained and untrained groups. These findings highlight the importance of adaptive sensory integration and suggest that multiple strategies may underlie improvements in balance ability.

In addition to these findings, we are also exploring the potential of postural biofeedback training to help maintain or improve mental health. To facilitate broader and more accessible use, we are currently developing a method that enables postural biofeedback training to be conducted using only a smartphone.

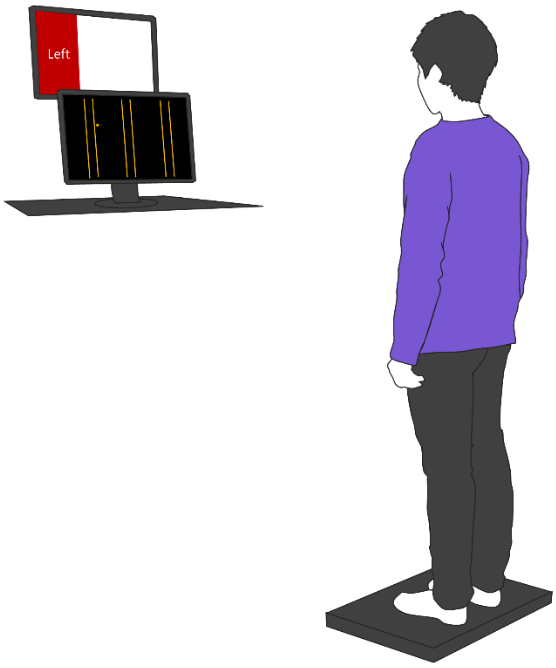

Fig 1. An example of postural biofeedback training that provides CoP information measured by a force plate.

Keywords: Postural Control, Center of Pressure

References

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