Introduction to the Mobile Robotics Lab (OTA Lab)
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Human-Artifactology Research Division,
Research into Artifacts, Center for Engineering (RACE) ,
The University of Tokyo

Research Complex 5F, Kashiwa Campus,
Kashiwanoha 5-1-5, Kashiwa, Chiba 277-8568, Japan

URL: http://otalab.race.u-tokyo.ac.jp

Members

Professor	Jun OTA
Research Associate	Taiki OGATA
Postdoc Researchers	Shouhei SHIRAFUJI
Doctoral Course Students	Veerachart SRISAMOSORN, Kohei KAMINISHI, Hamdi SAHLOUL, Akihisa TAKEDA, Changxiang FAN, Reiko INOUE, Sixiao GAO, Chingszu LIN, Enrico PIOVANELLI, Dongdong LI
Master Course Students	Shunsuke KANNO, Zhenyi CHEN, Yibin CHEN, Yalcin AKIN, Tatsuma ITO, Kazuki KIRIU, Chunyin ZHANG
Undergraduate Students	Kaori FUJIKAWA, Akihide TAKEUCHI
Secretaries	Mika TAMURA, Ayako NAKAMURA

Research Topics of the 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, evolutionary computation, control theory, and so on.

Our final target is to establish a design methodology for 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.

The details of our research are listed below.

Multi-agent robotics and mobiligence
Development of small mobile robot for manipulation of heavy object
Teaching Multiple Robots Based on Robots Capabilities
Foreground Segmentation with Efficient Selection from ICP Outliers in 3D Scene
Automatic Face Tracking System using Flying Blimp for Estimation of Elderly People’s Emotion

Design of large-scale production/transport systems
Automatic Design of Image Acquisition Environment and Recognition Process for Picking

Human analysis
Temporal Co-creation between Multi-People
A simulator robot reproducing patient's variability for nursing students to learn transfer skill
Development of Belt Locking Mechanism for Lumber Assistive Device
Source Localization of Individual Forearm Extensor Muscles using HighDensity Surface Electromyography
Modeling Human Stance Postural Control through Forward Dynamics Simulation

Development of small mobile robot for manipulation of heavy object

Adopting robots to replace human labor in the manipulation of heavy loads laying at home, in offices or in other environments, human could be emancipated from such kinds of heavy works. However, big scale of transportation robots used in factories are not appropriate be applied as such environments are narrow generally. On the other hand, robots that are designed for certain kinds of manipulation cases may not be practical as objects and environments in the manipulations are various. In this way, we aim to realize the manipulation of heavy objects by small scale of mobile robots.

In order to manipulate the heavy load, it is necessary to exert a sufficient large force on the object to some extent. Anyway, in the case of a small robot, the possibility exists that the robot may flip over due to the reaction force when it exerts relatively large force to the object. Once the robot flip over, it would be extremely difficult to continue the manipulation, so such cases should be prevented. If the robot flipping over could be prevented, then the manipulation of object with all the above-mentioned difficulties could be realized. Furthermore, with cooperation of multi small mobile robots, such as tilting the objects and inserting carts to the bottom[1], then a variety of manipulations would be able to be conducted.

In this research, the mechanism of manipulator shown in Fig 1 is proposed[2], which could exert large scale of force while preventing the robot flipping over. The manipulator is actuated by a linear motor, and works with its two tail ends, which are fixed with passive joints, contacting with the object and the floor. In this way the reaction force acts in the opposite direction of actuating force so that the moment that makes the robot flip over would not occur. Therefore, the robot does never flip over regardless the scale of output force. Furthermore, a compact mobile robot equipped with this manipulator is also developed in this research (Fig 2) [3].

Since the manipulator joints are passive, the robot could not adjust the output position and direction of force in manipulation. Therefore, it is important to properly plan the manipulation for object before conducting the manipulation. In this research the planning method is proposed to determine the manipulation for an object with known dimensional and weight parameters. Firstly, the force exerted on the object is analyzed, and then the number of robots needed for tilting manipulation is determined. In the case of only one robot engaging in the manipulation, the conditions to tilt object without sliding could be obtained through the force analysis for robot. In the case that two robots engaging in the manipulation, adopting the second robot to support the object and with the condition that the robots do not slip as a constraint, the optimal manipulation planning with minimum force could be obtained. Applying the above mentioned method, an object with the weight of 40.0*kg* is tiled actually, as shown is Fig 3[3].

Keywords: mobile robot, large force, pushing manipulation

Reference

[1] F. Ohashi, K. Kaminishi, J. Heredia, H. Kato, T. Ogata, T. Hara and J. Ota: “Realization of Heavy Object Transportation by Mobile Robots Using Handcarts and Outrigger,” ROBOMECH Journal, 3:27 DOI 10.1186/s40648-016-0066-y, 2016.

[2] S. Shirafuji, Y. Terada and J. Ota: “Mechanism Allowing a Mobile Robot to Apply a Large Force to the Environment,” Proceedings of the 14th International Conference on Intelligent Autonomous Systems, pp 795-808, 2016.

[3] 伊藤 達真，白藤 翔平，太田 順:”協調による重量物操作をおこなうための小型移動ロボットの開発,” 日本機械学会ロボティクスメカトロニクス講演会講演概要集, Vol.2017, 2017.

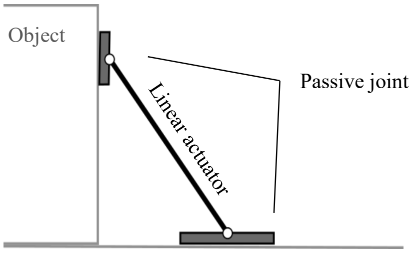


Fig 1. Mechanism to prevent robot flipping over with reaction force

Fig 2. Small mobile robot

Fig 3. Tilting manipulation for heavy object with 2 mobile robots

Teaching Multiple Robots Based on Robots Capabilities

In this study, we have focused on the problem how a user teaches the motion of the multiple robots by his/her demonstration, and have proposed the easy way to separate the user's demonstration into several motions and translate them into the motion of the multiple robots. The proposed methodology is as followings: First, the user show the motion needed to accomplish the given task using the data grove (Figure 1). The proposed system in our study derives the number of robots needed to accomplish the task according with the variety of the manipulation in the task. Furthermore, the motion for each robot is determined by the user through the developed GUI based interface based on the number of robots. Finally, the motion of robot determined by above procedure is modified to more efficient trajectories of the robots by the system. We demonstrated four types of tasks; lifting up objects, inclining an object, and unfolding a chair, using the proposed method, and confirmed the motion of the multiple robots can be generated from the demonstration of the user. Furthermore, we validated the proposed method can generate the motion of multiple robots faster than previous works by the experiments.

Keywords: mobile robot, cooperating manipulation, teaching

Reference

1. Figueroa Heredia,Jorge David, Sahloul,Hamdi, & Ota,Jun. (2016). Teaching mobile robots using custom-made tools by a semi-direct method, Journal of Robotics and Mechatronics, 28(2), 242-254.
2. Jorge David Figueroa Heredia, Jose Ildefonso U. Rubrico., Shouhei Shirafuji, and Ota Jun. (2017). Teaching Tasks to Multiple Small Robots by Classifying and Splitting a Human Example, Journal of Robotics and Mechatronics

Figure 1 *Demonstration of unfolding the chair by the user.*

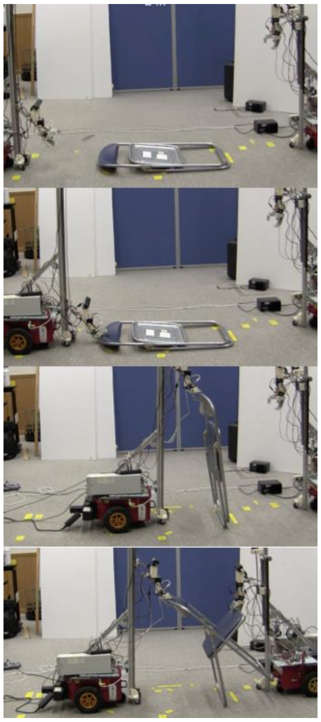


Figure2 Motion of multiple robots generated by the proposed system.

Foreground Segmentation
with Efficient Selection from ICP Outliers in 3D Scene

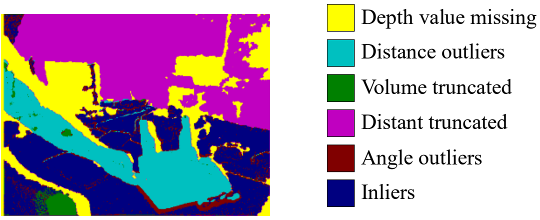
Foreground segmentation serves in reconstructing 3D models of moving objects in the scene. The foreground appears as a secondary outcome indicated by outliers of the Iterative Closest Point (ICP). To form the foreground, many studies have filtered outliers by noise-removal approaches such as morphological filtration or graph optimization. They have not considered constraints rejecting these outliers, and just handled ICP outliers all together.

This study constructs 3D reconstruction of the environment using a moving RGB-D sensor. Alignment of new frames to the fused surfaces is achieved by ICP algorithm. Foreground objects are recovered from ICP outliers (*Fig. 1.b*) after considering its most relevant segments. The segmented foreground could be tracked in separated volumetric fusion to construct foreground objects independent from the static reconstruction. This would enable interaction and virtual reality applications.

By tagging five different types of ICP outliers, we found out that noise-reduced foreground is located mainly in points violating distance constraint (*Fig. 1.c*). We propose a real-time method with an increase of 12% in quality (*Fig. 2*) using only bilateral filtration of distance outliers and distance truncation. Further details are available in the method's paper[1].

Our results suggest excluding distant depth points as well as angle/volume outliers from foreground segmentation to enhance processing time and quality. With that improvement, Graph-based refinements (e.g. GrabCut) are not required as well. Future work includes segmenting objects from the static environment once they start displaced.

(a) RGB frame (b) ICP Outliers



(c) Noise reduction by sub-outliers selection

Figure 1. Dataset frames and ICP outliers resulting from depth-frame alignment. (a) An RGB frame capturing some objects in-motion. (b) Corresponding ICP outliers. (c) Colored map showing distance outliers (in eggshell-blue color) used in proposed method.

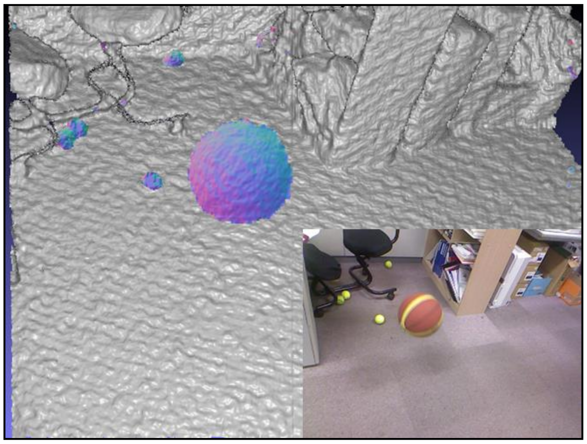


Figure 2. *Main*: A Phong shading surfaces of a reconstructed environment with the foreground represented as color-coded surface Normals. Proposed method results demonstrate a clean foreground of some balls while bouncing in the scene. *Side*: the corresponding RGB frame.

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[1] Hamdi Sahloul, Jorge Figueroa, Shouhei Shirafuji, and Jun Ota, "Foreground segmentation with efficient selection from ICP outliers in 3D scene," in *2015 IEEE International Conference on Robotics and Biomimetics (ROBIO)*, Zhuhai, China, Dec 2015, pp. 1371-1376.

Automatic Face Tracking System using Flying Blimp for Estimation of Elderly People's Emotion

For health care provided to elderly people or people with some mental disorders, patients' emotion needs to be observed regularly. The current practice uses a number of staff to observe their faces and use smile as the indicator. However, the ratio of staff to patients is not enough and the task requires regular observation, resulting in inefficiency, ineffectiveness, and fatigue of the caregivers. Therefore, a system for tracking people's face and processing for their emotion is necessary for this task. This research proposes the use of environmental cameras together with mobile cameras to track people's face to obtain their facial images.

In the previous system, a quadrotor equipped with small video camera was used to follow and track people's face. Xbox 360's Kinect cameras were installed in the environment to cover the area for localization of person and quadrotor, and control the quadrotor to be in front of the person at a constant distance. The system could perform tracking of person in a 3-by-3.5-meter area, with limitations of quadrotor's short battery life and noise caused by vibrating system used to cancel interferences among Kinects. A new system is proposed with blimp filled with lighter-than-air (LTA) gas to perform face tracking, and multiple fisheye cameras attached to the ceiling for locating position of people and blimp (see Fig.1). LTA gas's buoyancy makes hovering possible without the need of constant propulsion, reducing power consumption as well as noise created by propellers. The blimp also provides safer platform and is friendlier to people. The prototype of the blimp is shown in Fig.2.

Keywords: blimp, airship, fisheye cameras, human tracking, face tracking

Reference

[1] Srisamosorn, V., Kuwahara, N., Yamashita, A., Ogata, T., and Ota, J. "Design of Face Tracking System using Environmental Cameras and Flying Robot for Evaluation of Health Care". *Digital Human Modeling: Applications in Health, Safety, Ergonomics and Risk Management. DHM 2016. Lecture Notes in Computer Science, vol 9745. Springer, Cham*, pp. 264-273, Jul 2016.

[2] Srisamosorn, V., Kuwahara, N., Yamashita, A., Ogata, T., and Ota, J. "Design of Face Tracking System Using Fixed 360-Degree Cameras and Flying Blimp for Health Care Evaluation". *Proceedings of the 4th International Conference on Serviceology (ICServ 2016)*, pp. 63-66, Jul 2016.

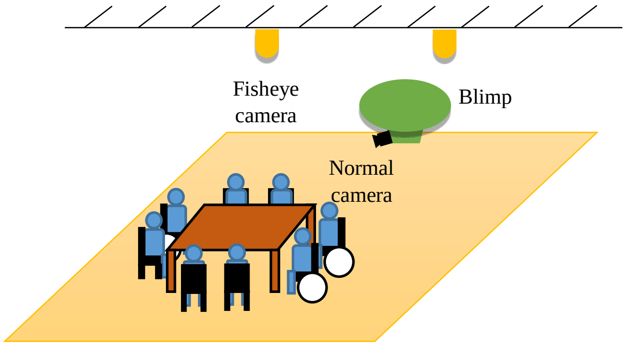


Fig. 4 System of blimp and fisheye cameras in elderly nursing home

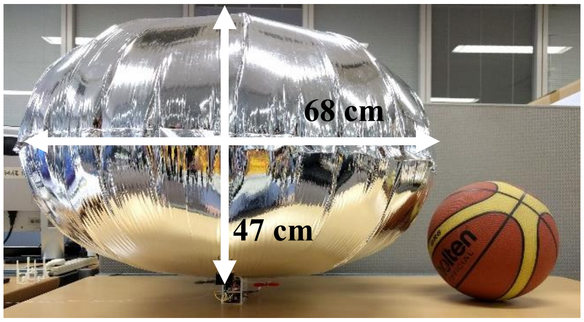


Fig. 3 Prototype of the blimp compared to a basketball

Automatic Design of Image Acquisition Environment and Recognition Process for Picking

Recently, to increase production capacity and/or to reduce production cost, image recognition technique is actively used in manufacturing system such as product assembly and inspection. First, it is necessary to design image acquisition environment to construct the image recognition system. Then, the process to recognize target objects, such as type, position and angle is needed to design. The recognition process usually consists of three steps: image conversion, feature extraction and identification. There are vast amounts of combinations of parameters in image acquisition environment and recognition process. In addition, the parameters included in image acquisition environment and recognition process mutually depend. Therefore, it requires long-term to design whole recognition system even for experts.

The purpose of this study is to automatically design the image acquisition environment and the recognition process for picking system (Fig. 1). For picking, to recognize the kind, position and angle of target objects is necessary. The image acquisition environment included distance between target objects and camera and intensity of RGB light. For recognition process, we used method based on local features and targeted the automatic design of image-conversion-parameters and identification using the local features. This automatic design was formulated as optimization problem and the problem was solved by metaheuristic method. For the optimization calculation, the experiment-based optimization was used because there are some uncertainties of environment in the real world. For the uncertainties, it is too difficult to solve this problem only using theoretic and/or computational methods. Fig. 2 and 3 show conceptual image of the experiment and proposed algorithm of the experiment-based optimization respectively. As the results or evaluation experiment, sufficient recognition accuracy was obtained within a reasonable time.

Key words: automatic design, optimization, image recognition, image acquisition environment

Reference

[1] K. Tsujimoto, *et al*.: "Simultaneous Design of Image Conversion Parameters and Classifier in Object Recognition for a Picking Task," Proc. Int. Conf. Robotics Biomimetics (ROBIO2014), pp. 457-462, 2014.

[2] T. Yukisawa, *et al*.: Automated Design of Image Recognition System Including Image Acquisition Environment for Picking, Proc. JSPE Semestrial Meeting 2016 JSPE Spring Conference, Chiba, March, 15–16, p. 155, 2016 (*in Japanese*)

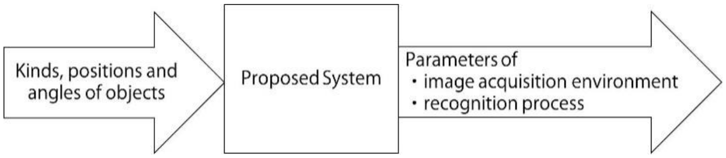


Fig. 1 Problem setting

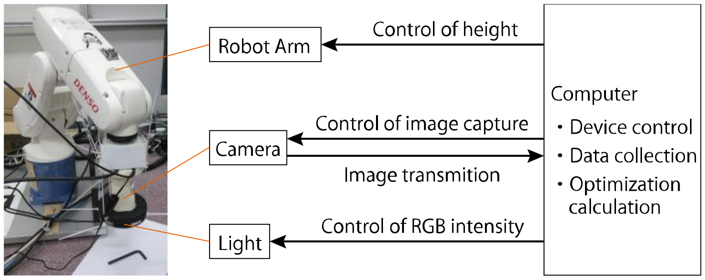


Fig.2 Conceptual image of proposed experiment-based optimization

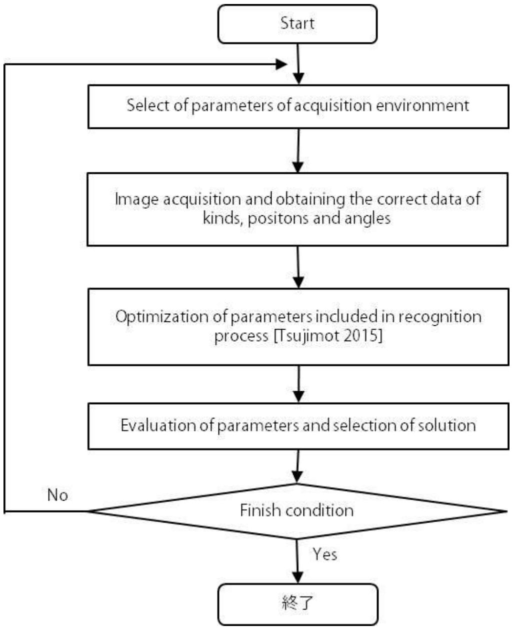


Fig. 3 Proposed algorisms

Temporal Co-creation between Multi-People

As evidenced in music ensemble, dance and sports, people cooperatively produce rhythm with other people. Such temporal co-creation between multi people includes many time delays: delays included in signal processing, multi-modal integration, sensory-motor coordination and cooperation with other people. Despite of such delays, people generate movement cooperatively with others in real time. To investigate the characteristics of temporal co-creation between people is important not only to understand human communication but also to achieve temporal co-creation between human and artifacts.

We conducted a psychological experiment. In the task, two mutually isolated followers simultaneously synchronized by finger tapping with a human leader or metronome producing constant tempo. The followers performed this task with or without tapping timing information of the other follower. The leaders were asked to tap their finger to keep constant tempo with or without the tapping time information of followers. Negative asynchronies (NAs) were observed under all leaders conditions. That is, the tap timings of the followers preceded those of the leaders. The amount of NA under human leader conditions was smaller than that under metronome condition. In addition, the followers predictively synchronized the human leaders while they synchronized the metronome to follow it up.

Keywords: Temporal co-creation, Multi-people communication, Cooperative rhythm production

References

1) T. Ogata, T. Katayama, Y. Miyake and J. Ota, Cooperative Rhythm Production between Three People through Auditory Signals. In Proceedings of 23rd International Symposium on Micro-Nano Mechatronics and Human Science, pp. 456—459, Nagoya, Nov. 2012.

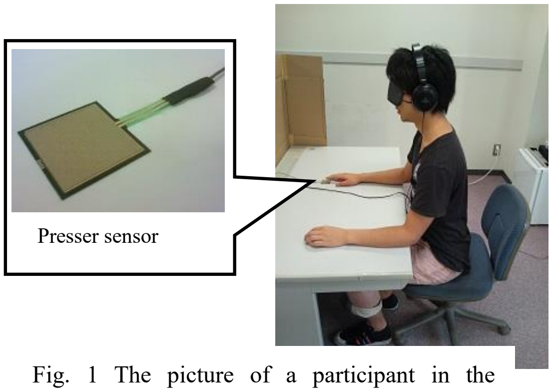


Fig. 1 The picture of a participant in the experiment and the presser sensor to measure the timing of the tapping

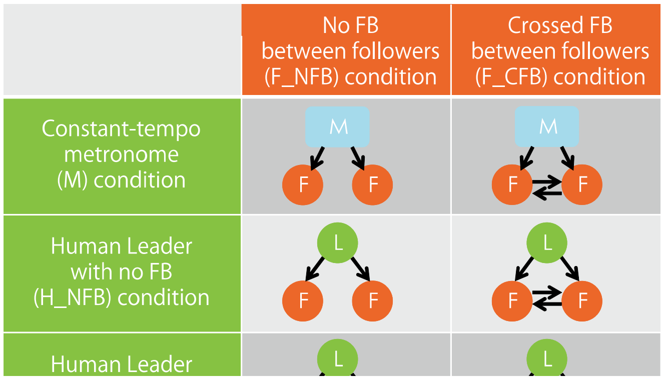


Fig. 2 The conditions of a leader who keeps the constant tempo and followers who cooperatively produce rhythm to synchronize with the leaders. The arrows indicate presentation of stimuli of metronome or other peoples' tapping timing. FB means feedback.

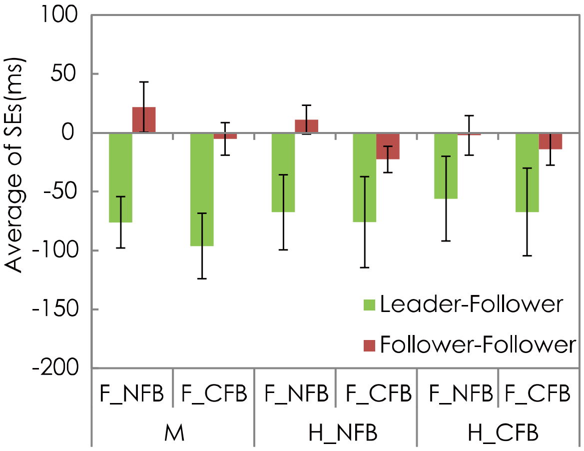


Fig. 3 Averaged synchronized errors (SEs). The followers tended to tap before the leaders.

A simulator robot reproducing patient's variability for nursing students to learn transfer skill

Recently, with aged society and diversified diseases, nurses are required for high proficiency and an ability to handle various patients. However, the present education is difficult to reach such need due to the difficulty to access various patients as in hospital. To improve the patient transfer skill of nursing education students, we developed a robot patient that can simulate three categories of patients: patients whose movements are affected by paralysis, patients whose movements are sensitive to pain with painful expression, and patients whose movements are constrained by medical devices. The students are expected to learn the skills required for interacting with various patients by practicing with the robot that imitate different patients.

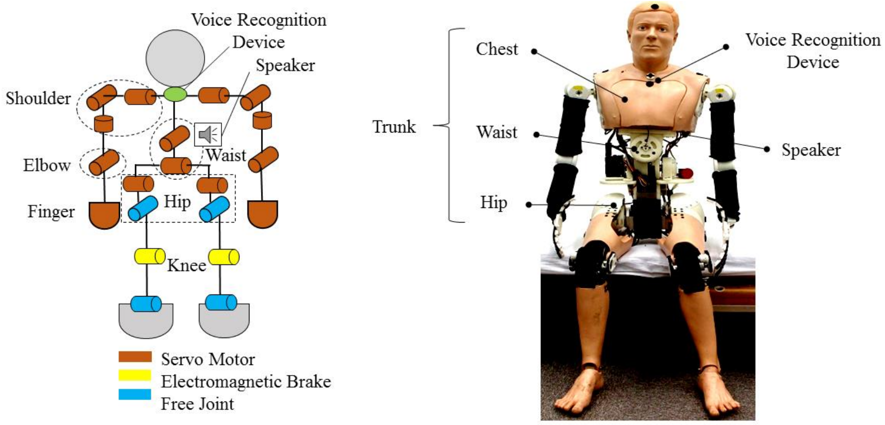
To simulate trunk movements, novel waist and hip joints with hardware-inherent compliance and force sensing capability were proposed. In addition, control methods of these three categories of patient were developed and the parameters were tuned based on actual patient videos. To evaluate the developed robot, the experiment with nursing teacher was conducted firstly to obtain the validity of robot. The nursing teachers performed trials of transferring the robot patient as they would transfer an actual patient. The nursing teachers scored the robot patients based on a checklist. Moreover, subjective evaluations of a questionnaire were performed by the nursing teachers. The results showed that the nursing teachers performed most of the required skills of the checklist and agreed regarding the learning effectiveness of the robot. They recommended training nursing students using the robot patient in the questionnaire.

Key Words: Robot patient, Nursing education, Skill acquisition, Paralysis simulation, Various type of patients

Reference:

[1] Z. Huang, T. Katayama, M. Kanai-Pak, J. Maeda, Y. Kitajima, M. Nakamura, K. Aida, N. Kuwahara, T. Ogata and J. Ota, “Design and evaluation of robot patient for nursing skill training in patient transfer,” *Advanced Robotics*, vol. 29, no. 19, pp. 1269-1285, 2015.

[2] T. Ogata, A. Nagata, Z. Huang, T. Katayama, M. Kanai-Pak, J. Maeda, Y. Kitajima, M. Nakamura, K. Aida and J. Ota, “Mannequin system for the self-training of nurses in the changing of clothes,” *Kybernetes*, vol. 45, no. 5, pp. 839-852, 2016.



(a) (b)

Fig.1. Developed robot patient (a) joint configuration and (b) appearance

Development of Belt Locking Mechanism for Lumber Assistive Device

Disorders such as the low back pain caused by the physical burden in daily works including nursing is a serious social problem. It has been pointed out that one of the factors which causes the low back pain is the accumulative load to the lumber by working in an unnatural posture such as a stooping posture for a long time.

In this study, we have developed the assistive device to support the user's weight using belts attached on the lumber in order to prevent the low back of the nurses caused by that they keep the stooping posture. For realizing the assistive device which mechanically locks the motion of the lumber using a belt while the user is in the stooping posture and release the constraint after the work is finished, we proposed a novel locking mechanism for a belt. In order to lock the belt, the proposed locking mechanism uses the large frictional forces caused by overlapping the belt on the frictional body as shown in Fig. 1, and the mechanism can cancel out the infinite tensile force applied to the belt in theory. We also proposed the way to unlock the belt by oscillating the belt and reducing the frictional coefficient. The mechanism was experimentally validated using the prototype of the proposed mechanism (Fig. 2). Currently, we are analyzing the efficient displacement of belts to support the user's weight and developing the assistive using this proposed locking mechanism for a belt.

Keywords: assistive device for lumber, locking mechanism for a flat belt

Reference

1. Matsui,Naotaka, Shirafuji,Shouhei, and Ota,Jun. (2016). Locking mechanism based on flat, overlapping belt, and ultrasonic vibration, Proceedings of the 2016 IEEE International Conference on Robotics and Biomimetics (ROBIO 2016), (pp.461-466). Qingdao, China

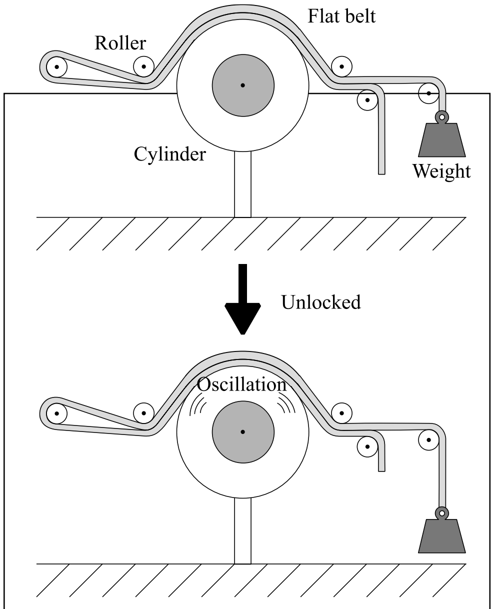


Fig. 1 *Mechanism to switch the state the belt is locked or unlocked.*

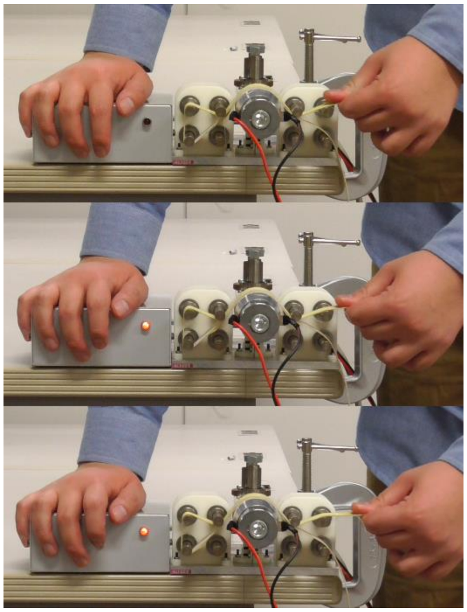


Fig. 2 *Demonstration to lock the belt uning the developed mechanism.*

Source Localization of Individual Forearm Extensor Muscles using High-Density Surface Electromyography

The limitations of conventional surface electromyography (sEMG) cause it to be unsuitable for use with the deep and compact muscles of the forearm. However, while source separation and localization techniques have been extensively explored to identify active sources in the brain using electroencephalography (EEG) signals, these techniques have not been adapted for identifying active sources in muscles using sEMG signals, despite being of a similar premise.

Our research explores the adaptability of conventional EEG source localization techniques (Figure 1) to identify active muscles within the forearm. Experiments consisted of controlled, isometric wrist and finger movements, with data obtained by high-density surface electromyography (Figures 2). The localization methodology consists of separating the raw sEMG signals using independent component analysis (ICA), estimating subject-specific a physics-based forward model through MRI tissue segmentation, and then correlating the obtained lead field matrix with the ICA mixing matrix. Localization was evaluated based on the accuracy of the estimated ECD source position with respect to the known active muscles.

Keywords: electromyography, source localization, source separation

Reference

Su,Becky, Shirafuji,Shouhei, Oya,Tomomichi, Ogata,Yousuke, Funato,Tetsuro, Yoshimura,Natsue, Pion-Tonachini,Luca, Makeig,Scott, Seki,Kazuhiko, & Ota,Jun. (2016). Source separation and localization of individual superficial forearm extensor muscles using high-density surface electromyography, Proc. IEEE Int. Symp. Micromechatronics and Human Science (MHS2016), (pp. 245-250). Nagoya.

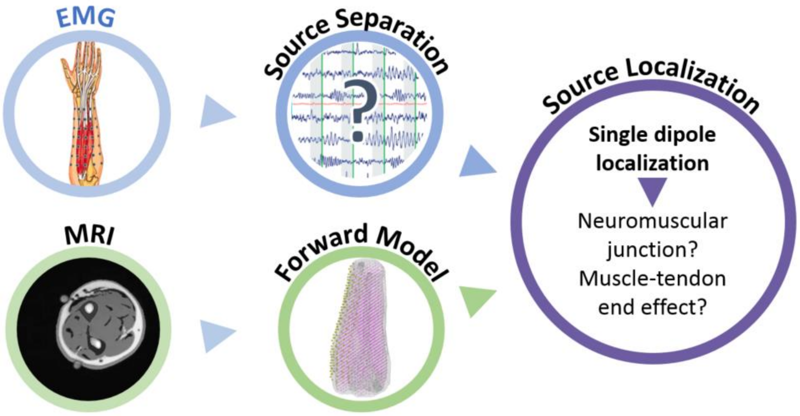


Figure 1. EEG-adapted source localization methodology.

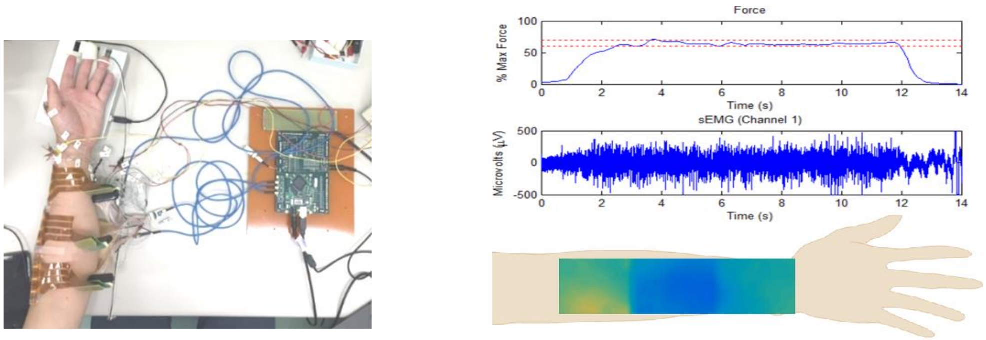


Figure 2. Experimental set-up (left), and example data obtained: force vs. time (top right), 1-channel sEMG vs time (middle right), and sEMG intensity color map (bottom right).

Modeling Human Stance Postural Control through Forward Dynamics Simulation

Stance postural control, which allows individuals to maintain an upright stance, is one of the most important and basic requirements for a comfortable life. Most previous literature used an inverted pendulum without muscles to represent human body, which is not physiologically plausible. In addition, inverse dynamics simulation was used to identify the hypothetical neural controller models based on experimental data. The method only reproduce the experimental data and cannot prove whether or not the proposed neural controller model is correct. Modeling human postural control by musculoskeletal forward dynamics simulation is necessary.

We propose a neural controller model (Fig. 1) to keep a musculoskeletal model (Fig. 2) in a stance posture. This model consists feed-forward control to send constant necessary muscle activations for stance and feedback control based on multisensory inputs. The parameters in the controller are designed by optimization of energy consumption during stance. As a result, the proposed model can simulate human-like muscle activations as well as activation change for different sensory input conditions, indicating that the proposed model is physiologically plausible. Currently, we use this controller to simulate the upright standing against disturbances.

Keywords: postural control, musculoskeletal model, biological simulation

Reference

1. Jiang,Ping, Chiba,Ryosuke, Takakusaki,Kaoru, & Ota,Jun. (2017). A postural control model incorporating multisensory inputs for maintaining a musculoskeletal model in a stance posture. Advanced Robotics, 31 (1-2), 55-67. doi: 10.1080/01691864.2016.1266095.

2. Jiang,Ping, Chiba,Ryosuke, Takakusaki,Kaoru, & Ota,Jun. (2016). Generation of the human biped stance by a neural controller able to compensate neurological time delay. PLoS ONE, 11 (9): e0163212. doi:10.1371/journal.pone.0163212.

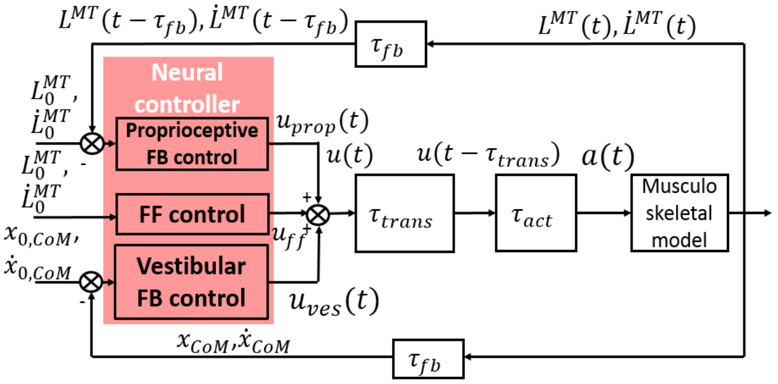


Fig. 1 Neural controller model. u : total control; a : activation; L^{MT}, L_0^{MT} : current and objective muscle length, respectively. $\dot{L}^{MT}, \dot{L}_0^{MT}$: current and objective muscle lengthening speed respectively. $x_{CoM}, \dot{x}_{CoM}$: displacement and velocity of center of mass in anterior-posterior direction; $\tau_{trans}, \tau_{fb}, \tau_{act}$: transmission, feedback and activation time delay.

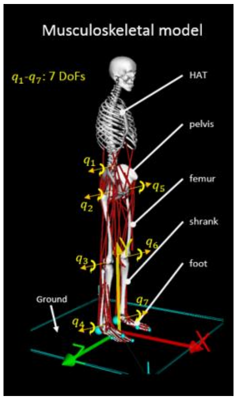


Fig. 2 Musculoskeletal model