Introduction to the Mobile Robotics Lab
(OTA Lab)
2018

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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

Automatic Face Tracking System using Flying Blimp for Estimation of Elderly People's Emotion
Foreground Segmentation with Efficient Selection from ICP Outliers in 3D Scene
Development and Manipulation Planning of Small Mobile Robot

Design of large-scale production/transport systems

Automated Design of the Field-of-View, Illumination, and Image Pre-processing Parameters of an Image Recognition System
Design of Buffer Size in Warehouse System

Human analysis

Musculoskeletal Simulation of Human Stance Postural Control
A Simulator Robot Reproducing Patient's Variability for Nursing Students to Learn Transfer Skill
Analysis of the Hand-arm Motion Using a Surface Electromyography with High-density Electrodes
Measurement Method for Lumbar Motion and Development of Lumbar Assistive Device
Recognizing Whether a Person is Eating Alone or Has Company by Using Wearable Devices

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., "Human-Tracking System using Quadrotors and Multiple Environmental Cameras for Face-Tracking Application," International Journal of Advanced Robotic Systems, 14(5): 1–18, Sep 2017.

[2] 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.

[3] 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.

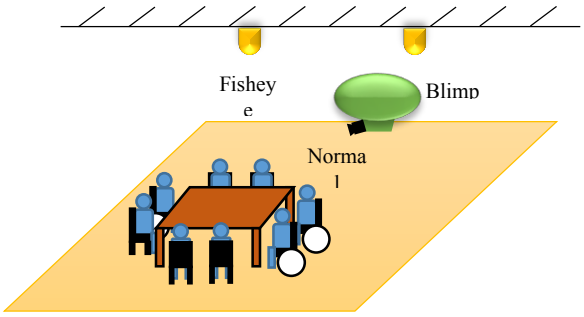


Fig 1. System of blimp and fisheye cameras in elderly nursing home.

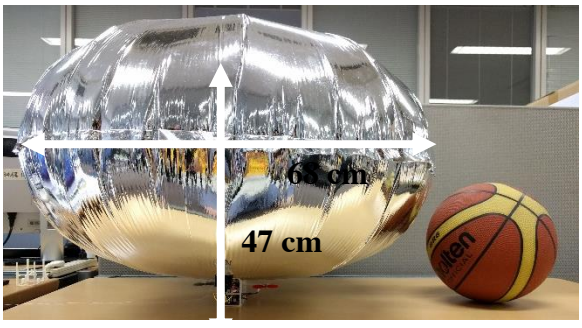


Fig 2. Prototype of the blimp compared to a basketball

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.

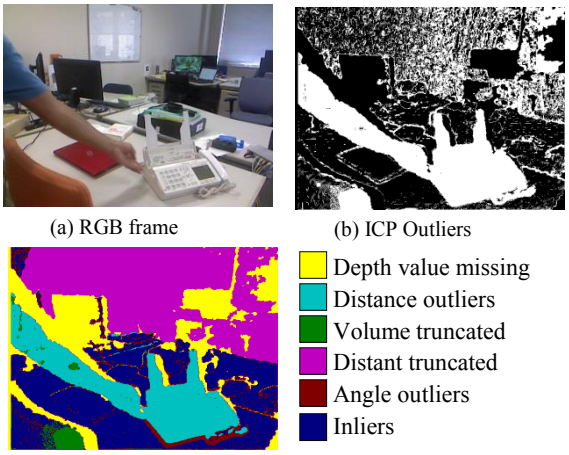
By tagging five different types of ICP outliers, we found out that noise-reduced foreground is located mainly in points violating distance constraint (Fig. 1.c). We propose a real-time method with an increase of 12% in quality (Fig. 2) using only bilateral filtration of distance outliers and distance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

Keywords: RGB-D, Dense 3D Reconstruction, Real-time, Foreground Segmentation

Reference

[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.



(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.

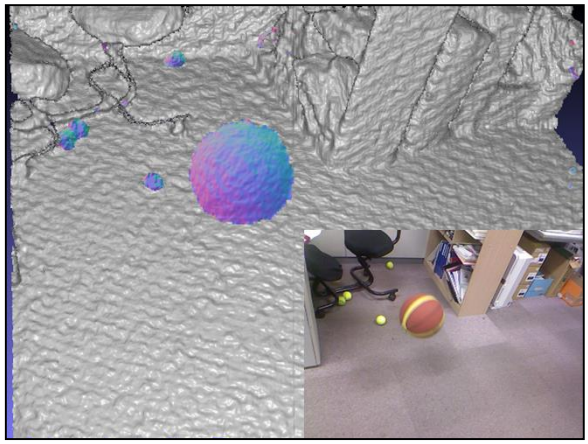


Figure 2. Main: A Phong shading surfaces of a reconstructed environment with the foreground represented as color-coded surface Normals. Proposed method results demonstrate a clean foreground of some balls while bouncing in the scene. Side: the corresponding RGB frame.

Development and Manipulation Planning of Small Mobile Robot

Adopting robots in the manipulation of big-sized objects in domestic environments, human could be emancipated from such trivial works. However, big-scaled robots are not available in narrow domestic spaces. Owing to the small size and motion flexibility, small mobile robots are desirable for such tasks. Working cooperatively, multiple robots can perform non-prehensile manipulation substituting manipulators.

In our earlier work, a small-sized mobile robot was developed [1], whose linear manipulator can exert a large force to push the object while robot flipping over can be avoided regardless the scale of output force. Various manipulations would be conducted by multiple robots cooperation, such as transferring objects [2].

To realize the cooperation among robots, manipulation planning in the multi-mode configuration space of object-robot system is needed. A hierarchical method is adopted in our work to deal with this multi-modal planning problem, as shown in Fig. 4. The modes in the multiple-robot non-prehensile manipulation is prior identified, with the determined amount of robots for manipulation stability. With the separated modes, sampled-based methods can be used for the planning task in the single-modes.

Since the manipulator joints are passive, the robot could not adjust the output position and direction of force in manipulation. Therefore, the optimal contact position of robot manipulator on a targeted object is derived in our work. Exerting contact on the optimal region of object surfaces, robots can work with highest efficiency of the output force to push the object, with a force balance achieved in the robot-object system.

Keywords: mobile robot, large force, manipulation planning, hierarchical planning, optimal placement

Reference

[1] S. Shirafuji, Y. Terada and J. Ota: "Mechanism Allowing a Mobile Robot to Apply a Large Force to the Environment," International Conference on Intelligent Autonomous Systems. Springer, Cham, 2016: 795-808.

[2] 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, 2016, 3.1: 27.

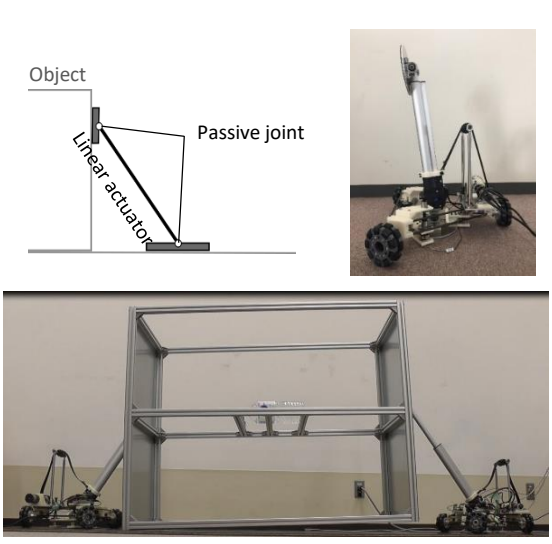


Fig 1. Developed mobile robot (above) and tilting manipulation using two mobile robots (bottom).

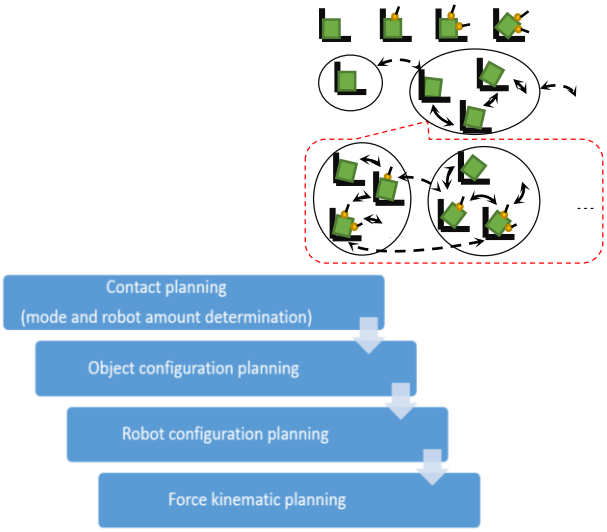


Fig 2. Hierarchical planning of multiple mobile robots.

Automated Design of the Field-of-View, Illumination, and Image Pre-processing Parameters of an Image Recognition System

As machine vision technology becomes more widely applied in industrial fields, designers have been attempting to tune the parameters for different kinds of vision system. In the object recognition system of a pick-and-place robot, for example, the camera position needs to be set to allow the robot to determine how many target objects have been captured, to adjust the illumination level, and to tune the image pre-processing parameters in the recognition algorithm. As this creates a number of conflicting variables, the design process must be reiterated until acceptable results are obtained. This is a time-consuming task, even when carried out by experts, and even a simple pick-and-place vision system usually takes several days to design.

In this study, we proposed a system that is capable of automatically designing the field-of-view of an image recognition system, based on the relationship between the camera and the target objects, the illumination conditions, and the image pre-processing parameters. We reformulated the design problem as an optimization problem, and used a multi-start nearest neighbor search method to solve it. Two evaluation experiments were conducted, with different distances between the target objects. The results demonstrated that the system was able to choose an appropriate field-of-view, illumination conditions, and image pre-processing parameters, taking account of the distance between target objects and the required accuracy of recognition.

Keywords: vision, recognition, parameter optimization, illumination, field-of-view, pre-processing

Reference

[1] T. Ogata, K. Tsujimoto, T. Yukisawa, Y. Huang, T. Arai, T. Ueyama, T. Takada and J. Ota, "Automated design of image recognition process for picking system," Int. J. Automation Technology, vol. 10, no. 5, pp. 737-752, 2016.

[2] T. Ogata, T. Yukisawa, T. Arai, T. Ueyama, T. Takada, and J. Ota, “Automated design of image recognition in capturing environment,” IEEJ Transactions on Electrical and Electronic Engineering, vol. 12, no. S2, pp. S49-S55. doi: 10.1002/tee.22551, 2017.

Y. Chen, T. Ogata, T. Ueyama, T. Takada, and J. Ota, “Automated Design of the Field-of-View, Illumination, and Image Pre-processing Parameters of an Image Recognition System,” Proceedings of IEEE Conference on Automation Science and Engineering, Xian, China, pp. 1079-1084, 2017.

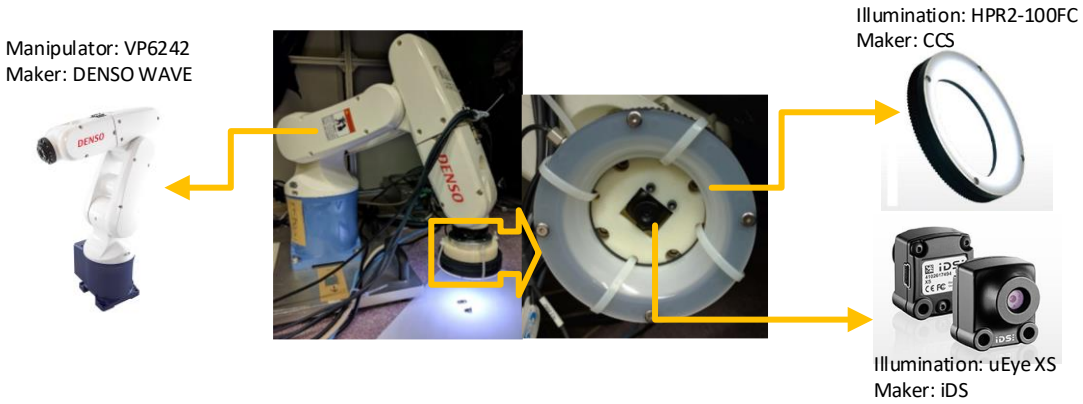


Figure 1. Experimental devices: ring-shaped illumination could change illumination from strength and color, manipulator make it possible to tune field-of-view by moving the position of camera.

Design of Buffer Size in Warehouse System

Buffers that are temporary storage area for jobs handover are widely applied in warehouse systems. Insufficient buffer size lead to too much congestion and blocking while excessive buffer size hamper the whole systems. In order to increase the working efficiency of the warehouse systems, proper buffers should be designed. However, jobs flow in real warehouse systems are very complex due to congestion and blocking, so it is difficult to measure the performance of the warehouse systems and evaluate the designed buffer size. In addition, more factors including blocking type and operation mechanism should be considered to analyze the different configuration of the systems, which increases the difficulty of performance measure of warehouse systems.

In this study, we proposed an automatic calculation algorithm to evaluate the performance of a warehouse system with designed buffer size. We modelled and solved the warehouse system based on queueing network theory and used Breath-First Search to make the whole modelling and calculation process automatically. Some numerical examples have been calculated and the calculation results were compared to the data from companies in related field (Figure 1). The results demonstrated the performance of warehouse systems including designed buffer with different configuration can be evaluated quickly with enough accuracy. In future, we will develop an automatic buffer design algorithm to design buffer size according to the calculation of performance of the systems with previous designed buffers.

Keywords: Warehouse system, Buffer Size, Blocking, Performance Measure, Automatic Calculation

Reference

[1] Brandwajn, A., & Jow, Y. L. L. (1988). An approximation method for tandem queues with blocking. Operations research, 36(1), 73-83.

[2] Schmidt, L. C., & Jackman, J. (2000). Modeling recirculating conveyors with blocking. European Journal of Operational Research, 124(2), 422-436.

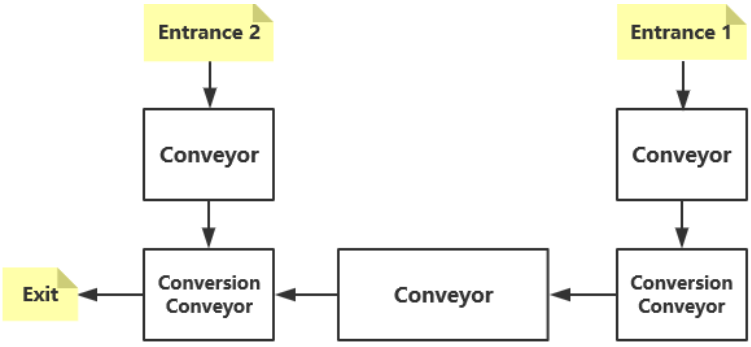


Fig 1. Numerical example: jobs enter the system from entrance 1 and entrance 2, and depart the system from exit. Arrows represent jobs flow direction. Throughput that is the rate at which jobs depart form the system was calculated.

Musculoskeletal Simulation of Human Stance Postural Control

Humans perform high-level stance postural control, which keeps their center of mass on their small base of support. Understanding the mechanism of the control is essential to providing effective rehabilitation. In attempts to model human postural control, torque-driven inverted pendulum models have been widely used as a human body. However, internal forces contributing to posture maintenance are not represented when using a torque-driven model. Muscle forces and three-dimensional location information of skeletal bones are to be treated.

We propose a neural controller model (Fig. 1) to keep a musculoskeletal model (Fig. 2) in a stance posture. This neural controller model consists of feed-forward control to send constant necessary muscle activations for stance and feedback control based on multisensory inputs. The neural controller model could simulate human-like muscle activations as well as activation change for different sensory input conditions. We also use this neural controller model to simulate a perturbed stance. We succeeded in maintaining the stance posture of a musculoskeletal model under multidirectional perturbations, and the trends of the magnitudes of muscle responses were consistent with experimental results in a previous study.

Keywords: postural control, musculoskeletal model, biological simulation

Reference

[1] P. Jiang, R. Chiba, K. Takakusaki, and J. Ota, "A postural control model incorporating multisensory inputs for maintaining a musculoskeletal model in a stance posture," Adv. Robot., vol. 31, no. 1–2, pp. 55–67, 2017.

[2] P. Jiang, R. Chiba, K. Takakusaki, and J. Ota, "Generation of the Human Biped Stance by a Neural Controller Able to Compensate Neurological Time Delay," PLoS One, vol. 11, no. 9, p. e0163212, 2016.

[3] K. Kaminishi, P. Jiang, R. Chiba, K. Takakusaki, and J. Ota, "Proprioceptive postural control of a musculoskeletal model against horizontal disturbances," in 2017 IEEE International Conference on Robotics and Biomimetics (ROBIO 2017), 2017, pp. 1270–1275.

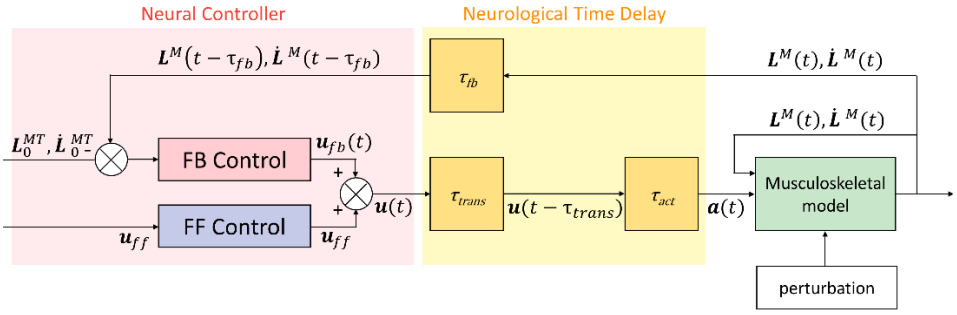


Fig 1. Developed mobile robot (above) and tilting manipulation using two mobile robots (bottomFig. 1 Neural controller. It is composed of feedback control based on muscle length and lengthening speed and feed-forward control of constant value. u: total control, a: activation,

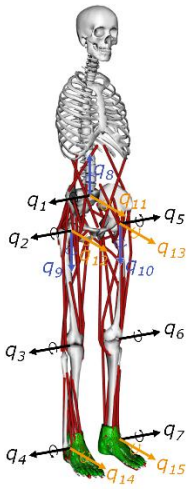


Fig. 2 Musculoskeletal model.

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.

Keywords: 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.

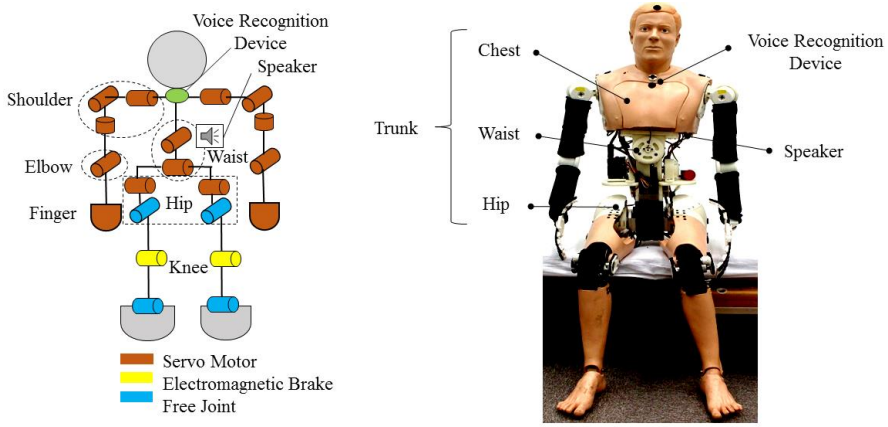


Fig 1. Developed robot patient (a) joint configuration and (b) appearance.

Analysis of the Hand-arm Motion Using a Surface Electromyography with High-density Electrodes

By measuring the surface muscle potential caused by human muscle activity using electrodes with high-density compared to a conventional surface electromyogram, spatially rich information about muscle activity can be obtained. On the other hand, movement of the hand is caused by the complicated cooperation of muscles, the surface muscle potential generated by these activities is very cumbersome and difficult to handle. Therefore, in this research, by analyzing information obtained from surface electromyography with high-density electrodes, we are conducting several studies to capture the phenomena occurring in the muscles during hand movement.

One of them is to estimate where the surface muscle potential originates from the forearm using a surface electromyography with high-density electrodes. In this study, we extended a method for determining signal sources of brain waves to identify the muscle activities of forearms and verified this by experiments. First, muscle potential on the forearm during the isometric motor task of fingers and wrists were using a high-density surface electromyogram (Fig. 1). For the identification of the signal sources, firstly the measured muscle potential is separated into independent signals by the independent component analysis, and a physics-based forward model of the forearm, which is the relation between the signal sources and the sensor points, is constructed from the MRI image for each subject. The relationship between the independent signals and the signal sources is obtained by analyzing this relationship. The estimated signal sources were evaluated on the proximity to the position of the muscle that caused the corresponding motor task, and the effectiveness of the proposed method was confirmed.

We are also working on the research to estimate the phenomena occurring in hand, especially the forces generated in the fingers, directly from the surface muscle potential measured with high-density surface electromyography. First, we measured the muscle potential with high-density surface electromyography and measured the force generated at the fingertip. We constructed an artificial neural network expressing the relationship between the potential and the force by the machine learning and then evaluated the accuracy of the model based on the determination coefficient between the estimated and the measured value. We clarified the possibility of estimation of force in each anatomical direction of each finger from the information of the high-density surface electromyography.

Keywords: Surface electromyography, Forearm, Muscle activity, Signal analysis

Reference

[1] Becky Su, Shouhei Shirafuji, Tomomichi Oya, Yousuke Ogata, Tetsuro Funato, Natsue Yoshimura, Luca Pion-Tonachini, Scott Makeig, Kazuhiko Seki, and Jun Ota: "Source Separation and Localization of Individual Superficial Forearm Extensor Muscles using High-Density Surface Electromyography," Proceedings of the IEEE International Symposium on Micro-NanoMechatronics and Human Science, Nagoya, Japan, pp.245-250, November, 2016.

[2] Kaori Fujikawa, Shouhei Shirafuji, Becky Su, Enrico Piovanelli, and Jun Ota: "Estimation of fingertip forces using high-density surface electromyography," Proceedings of IEEE International Symposium on Micro-NanoMechatronics and Human Science, Nagoya, Japan, pp.277-280, December, 2017

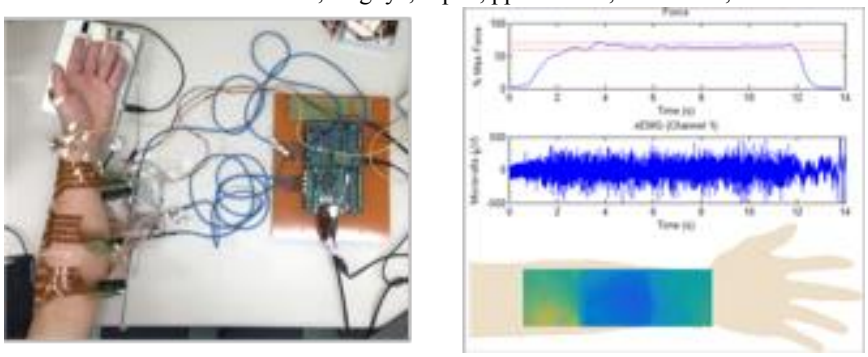


Fig 1. Experimental setup (left), an example of the measured force (upper right), an example of measured muscle potential (center right), and an example of colormap of measured muscle potential.

Measurement Method for Lumbar Motion and Development of Lumbar Assistive Device

Physical burdens caused by work in kinds of jobs including nurses, and diseases such as low back pain caused thereby are significant social problems. Among them, it has been pointed out that accumulation of burden on the low back by performing work in an unnatural posture such as a half-sitting posture for a long time is one of the causes of low back pain. In this research, we are conducting two studies with the aim of developing an assisting device that supports the lumbar.

One of them is the accurate measurement of lumbar spine motion. For a better lumbar support device, it is necessary to understand the kind of motion the lumbar spine makes during daily activities. In this study, regarding each lumbar vertebra as a rigid body, we propose a method to estimate the motion of these rigid bodies from the change of the contact point of overlapped two belts attached to the back. Based on the model shown in Fig. 1, we estimate the motion of the original rigid body by developing the sensor system that measures the change in the contact position as the rigid body transitions and rotations. We verified the effectiveness of this method by several experiments (Figure 2).

Together with the above development of measurement method, we also developed a device that supports the low back with a belt attached along the back when taking half-sitting posture or forward tilting posture for work such as nursing care. To realize such a device, we have proposed a mechanism for supporting the low back by mechanically locking the belt attached to the back in an arbitrary posture, and releasing this lock when the half-sitting work is over. The proposed mechanism is possible to support a theoretically infinite force with a small force because of the friction generated between the belt and the friction body by disposing of two overlapped belts. Besides, we proposed a method to change the friction coefficient by the ultrasonic vibration and change the locked state of the belt and confirmed the effectiveness of this system by experiment (Fig. 3).

Keywords: Estimation of lumbar motion, Assistive device for low back, Mechanism using blts

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), Qingdao, China, pp.461-466. December, 2016.

[2] Shouhei Shirafuji, Naotaka Matsui, and Jun Ota: “Novel frictional-locking-mechanism for a flat belt: Theory, mechanism, and validation,” Mechanism and Machine Theory, Elsevier Science B.V., vol.116, pp.371-382, 2017.

[3] Yalcin Akin, Shouhei Shirafuji, and Jun Ota: "Non-invasive estimation method for lumbar spinal motion using flat belts and wires," Proceedings of the IEEE International Conference on Robotics and Biomimetics, Macau, China, pp.171-176, December, 2017

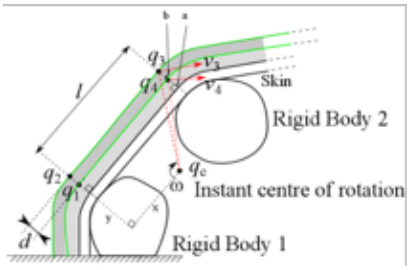


Fig 1. Model of the lumbar motion.

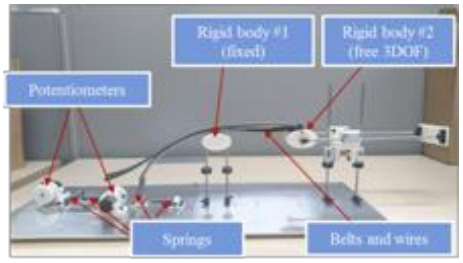


Fig 2. Experimental setup for evaluation of proposed method.

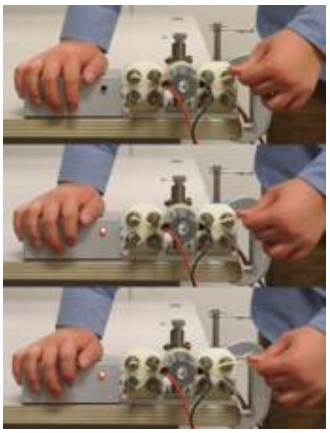


Fig 3. Proposed mechanism to lock the motion of a belt.

Recognizing Whether a Person is Eating Alone or Has Company by Using Wearable Devices

Mental health has received increasing attention in recent years, and research has been done on objectively measuring mental health. The mental health of a person is usually evaluated by the person's lifestyle such as their eating and sleeping habits. However, interaction with people is also important for mental health; the focus is largely on whether there is a correlation between mental health and eating, i.e., whether eating alone or has company is related to the mental health. Therefore, the aim of this research is to use wearable devices to recognize whether a person is eating alone or has company in daily life.

We hypothesized that we could use the differences in movements of the hands based on gesturing and in the access to the smartphone to recognize if a person is eating alone or has company. Therefore, recognition method using the data collected by watch-type device and the data collected by smartphone was proposed (Fig. 1). We calculated features indicating movements of the hand and access to the smartphone using the collected data, and we conducted the recognition using the calculated features.

Experiment was conducted to verify this method, and using the collected data, the recognition model was constructed for each participant. We got the accuracy of 96.3%, therefore the hypothesis was supported [1].

Keywords: eating alone, watch-type device, smartphone

Reference

[1] Kazuki Kiriu, Ochiai Keiichi, Akiya Inagaki, Naoki Yamamoto, Yusuke Fukazawa Masatoshi Kimoto, Tsukasa Okimura, Yuri Terasawa, Takaki Maeda, Jun Ota: "Recognizing Whether a Person is Eating Alone or Has Company by Using Wearable Devices," Proceedings of the 10th IPSJ International Conference on Mobile Computing and Ubiquitous Networking, 2017.

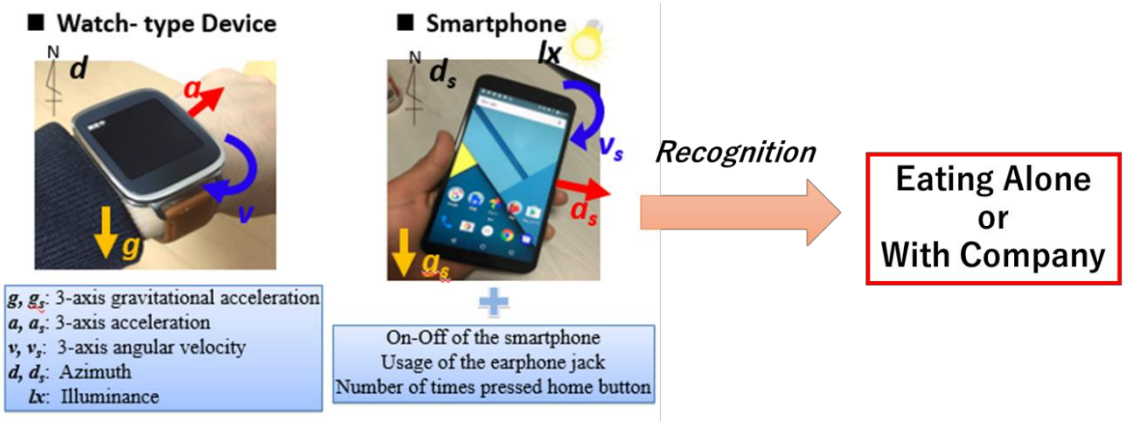


Fig 1. Recognition of the presence of the company at mealtime.