Introduction to the Mobile Robotics Lab (OTA Lab) 2020

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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 "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 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.

Design of robotics system

- Development and manipulation planning of small mobile robot
- Contact state estimation using motion
- Design of mechanism using optimization according to task

Design of large-scale production/transport systems

- Buffer design of warehouse system

Human analysis, service, and hyper-adaptability science

- Musculoskeletal simulation of human stance postural control for external forces
- Representation of postural abnormalities in Parkinson's disease patients using a computational model
- Development of the wearable device for measuring finger joint angle
- Method to estimate the muscle activation pattern from MRI and EMG
- Learning patient transfer skill by using a robot patient
- Multi-attention deep recurrent neural network for nursing action evaluation using wearable sensor

  (*Following research topics are studied by the collaboration with Dr. Tatsunori Hara (Project Associate Professor of Graduate School of Media and Governance, Keio University and Senior Project Researcher of School of Engineering, The University of Tokyo)*)
- Service ecosystem design using social modeling to incorporate customers' behavioral logic

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, because they can perform non-prehensile manipulation substituting manipulators by working cooperatively.

In our work, we adopted passive joints to design the mechanism of the multiple mobile robots [1,2], so as to realize the equivalent point—face contact model between the robots and the manipulated object. The costly controlling to maintain the object—robot contact could be avoided when manipulating the object. This simple contact model facilitated the manipulation planning, in which the contact state was required to be known to determine whether the robots provided adequate constraint for the manipulation.

In the manipulation planning, to deal with the distinct multi-level configuration space caused by the varying constraints in the robot-object system, a hierarchical method was adopted in our work. Defining a mode as a set of specific configurations that hold the same constraint, we specially focused on the modal planning, by which the manipulation action sequences could be determined to narrow down the configuration space for searching tasks [3]. Our proposed method determined the number of robots for manipulation stability, and investigated the mode transitions caused by the robots' motions and by the object's motions. With our method, the possible number of modes and their transitions was obviously reduced, and the determined mode sequences can be used to guide the further searching task for configuration planning.
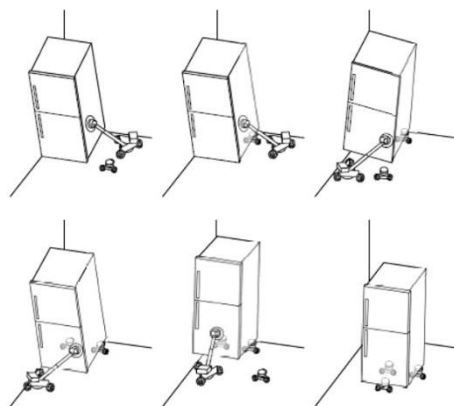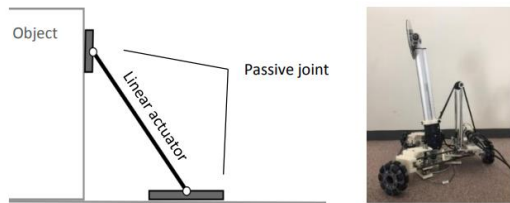

Figure 1. Constraints of the joints on the robotics leg using wires and non-circular pulleys.
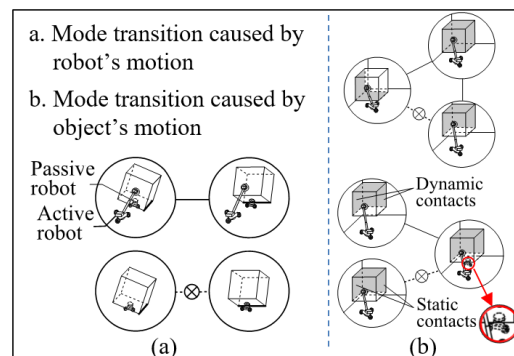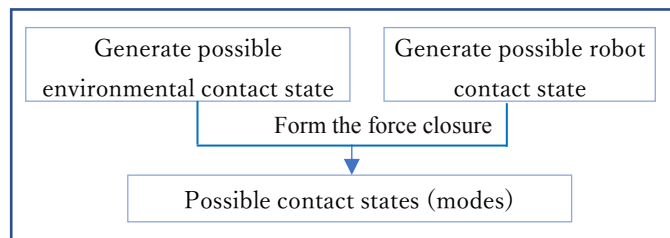

Figure 2. Mechanism to draw a letter on an egg-shaped object with less numbers of joints.

Keywords: mobile robot, simple contact model, manipulation planning, modal planning

References:
[1] S. Shirafuji, et al. Mechanism allowing large-force application by a mobile robot, and development of ARODA. Robotics and Autonomous Systems, 2018, 110: 92-101.
[2] T. Ito, S. Shirafuji, J. Ota. Development of a Mobile Robot Capable of Tilting Heavy Objects and its Safe Placement with Respect to Target Objects. In Proceedings of the 2018 IEEE International Conference on Roboics and Biomimetics (ROBIO2018), Kuala Lumpur, Malaysia, 12–15 December 2018; pp. 716–722.
[3] C. Fan, S. Shirafuji, J. Ota. Modal Planning for Cooperative Non-Prehensile Manipulation by Mobile Robots. Applied Sciences, 2019, 9.3: 462.

Contact State Estimation Using Motion

People can perform a variety of tasks by skillfully handling the contact between an object and its surroundings. For example, when loading and unloading goods in a warehouse, it is possible to save force compared to simply lifting the goods by sliding them. Such manipulation is also useful for robots.

To achieve such manipulation without applying unnecessary force, it is necessary to know the contact state (e.g., the surface or edge in contact) between the object and the environment. Therefore, it is important to estimate the contact state between the object and the environment based on the motion of the robot's hand.

In this study, we proposed a method for estimating the contact state between an unknown geometric object and an unknown geometric environment. We proposed an algorithm to estimate the contacting faces and edges from the motion of an object, and verified the method by experiments using a motion capture system.
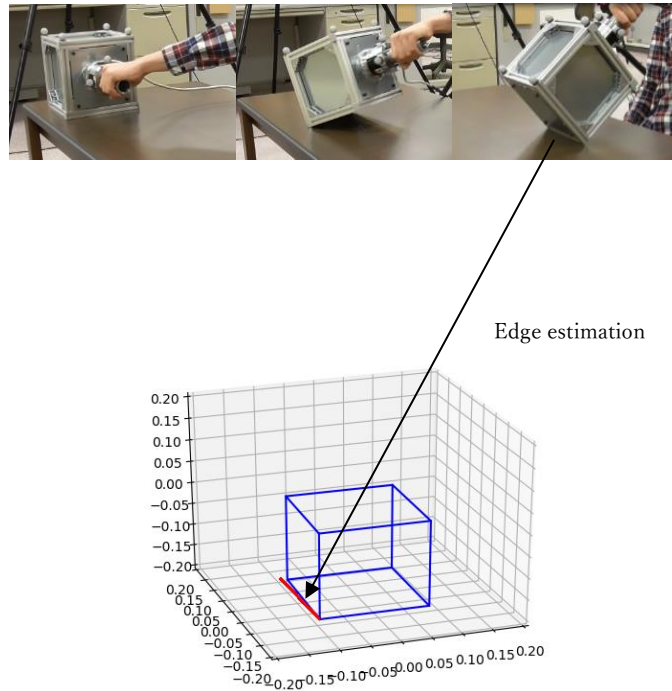

Figure 1. Experiment and result

Keywords: contact state estimation, compliant motion, manipulation

References:
[1] Ishikawa, S., Shirafuji, S. & Ota, J. (2019). Kinematics Analysis for Estimation of Contact Conditions in Teaching, Proceedings of the 2019 JSME Conference on Robotics and Mechatronics, Hiroshima, Japan, June 5-8, 2019

Design of Mechanism using Optimization According to Task

In the field of robotics, most of the studies focus on how to control the given mechanism to accomplish the target task. However, many tasks can be simplified or solved by preparing specified mechanism without sophisticated control method. Therefore, we are studying the methodology to derive the appropriate mechanism for a given task by calculation from the viewpoint of kinematics.

One of the outcomes of this study is the methodology to constrain the motion of a pair of revolute joints by a wire to generate the coordinated motion. We proposed the method to derive the shape of non-circular pulleys, which decides the route the wire, pass through, to realize the target coordinated motion of the joints [1]. An example of the applications designed by the proposed method is the leg mechanism of the robot, as shown in Fig. 1. This leg mechanism can move forward supporting its weight by the constraint on joints without controlling joints.

We also have proposed the methodology to decide the displacements of joints according to the task. We proposed the optimization method to decide the joint displacements of a manipulator that realizes the given target trajectory of its end-effector with less number of joints [2]. In the proposed method, the calculation of the errors between the target trajectory and resultant trajectory generated by design using the differential inverse kinematics realize the optimization with small calculation cost. Fig. 2 shows the manipulator, which we designed using the proposed method, can draw a letter on an egg-shaped object. This manipulator can draw the target letter on the curved shape only with three joints.
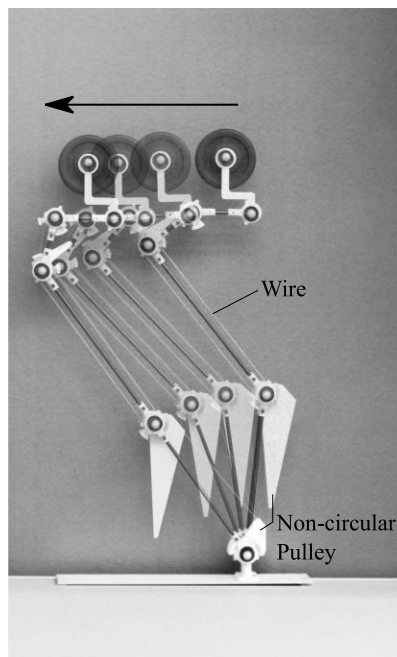

Figure 1. Constraints of the joints on the robotics leg using wires and non-circular pulleys.
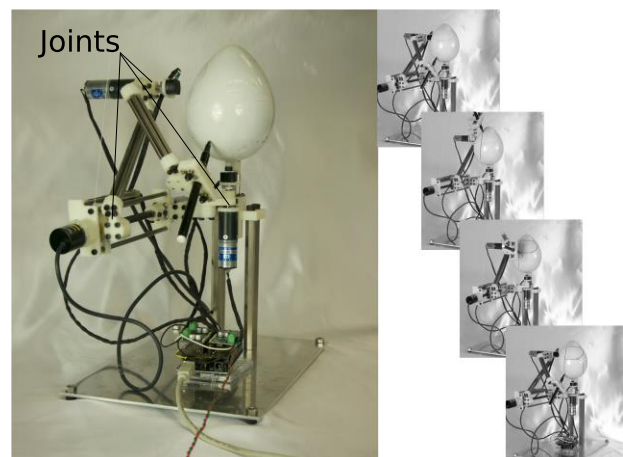

Figure 2. Mechanism to draw a letter on an egg-shaped object with less numbers of joints.

Keywords: robot design, optimization, kinematic synthesis, wire, non-circular pulley

References:
[1] Shouhei Shirafuji, Shuhei Ikemoto, and Koh Hosoda: "Designing Non-circular Pulleys to Realize Target Motion between Two Joints," IEEE/ASME Transactions on Mechatronics, vol.22 no.1, pp.487-497, 2016.
[2] Shouhei Shiarafuji and Jun Ota: "Kinematic Synthesis of a Serial Robotic Manipulator by Using Generalized Differential Inverse Kinematics," IEEE Transactions on Robotics, vol.35 no.4, pp.1047-1054, 2019.

Buffer Design of Warehouse System

Buffer design is a very important issue in the design, optimization and management of warehouse systems. In warehouse systems, buffers are used to temporary storage area for jobs handover. Excessive buffers increase system redundancy and waste cost, while insufficient buffers lead to blocking and low profits. Therefore, buffers should be designed properly. However, because of complex and consistently variable jobs flow in warehouse systems, both the modeling and buffer design become very difficult. In addition, other factors such as service disciplines increase the analysis difficulty of warehouse systems.

The purpose of this study is to efficiently determine suitable buffer update locations and increase proper buffer size in warehouse systems to satisfy the desired throughput. We proposed a bottleneck-based variable neighborhood search algorithm to allocate buffers and obtain buffer design solution of warehouse systems. In the algorithm, a queue module-based throughput calculation approach is proposed to evaluate the effectiveness of the buffer design solution efficiently. Numerical examples show that the proposed algorithm is applicable to design buffers for warehouse systems efficiently. In the future, we will improve the proposed buffer design approach and make it more applicable to very large-scale warehouse systems.
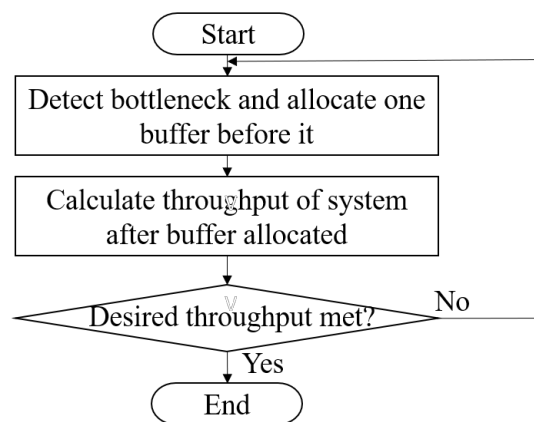

Figure 1. Framework of the proposed algorithm

Keywords: buffer design, warehouse systems, bottleneck, variable neighborhood search

References:
[1] Gao, S., Rubrico, J. I. U., Higashi, T., Kobayashi, T., Taneda, K., & Ota, J. (2019). Efficient Throughput Analysis of Production Lines Based on Modular Queues. IEEE Access, 7, 95314-95326.
[2] Gao, S., Higashi, T., Kobayashi, T., Taneda, K., & Ota, J. (2018). Fast buffer size design of production lines for meeting the desired throughput, Proceedings of the 2018 IEEE International Conference on Robotics and Biomimetics (ROBIO 2018), December 12-15, 2018, Kuala Lumpur, Malaysia, (pp. 1413-1418).
[3] Schmidt, L. C., & Jackman, J. (2000). Modeling recirculating conveyors with blocking. European Journal of Operational Research, 124(2), 422-436.

Musculoskeletal Simulation of Human Stance Postural Control for External Forces

When humans are subjected to external forces, they use their ankles and hips to balance themselves. It is called ankle strategy when only ankle movements are used, and hip strategy when hip movements are also used. These postural control strategies are used differently depending on the magnitude of the external force, but it is known that they are also used differently among individuals even when the magnitude of the external force is the same. How postural control strategies are used can be used as indicators, such as predicting falls. However, it is unclear how differences in any of the parameters between individuals will affect the way postural control strategies are used. We investigate that through forward dynamics simulations using musculoskeletal models and human experiments.

We first stood a musculoskeletal model (Fig. 1) using a neural controller model and moved the support surface in various directions [1]. We succeeded maintaining a standing posture of the musculoskeletal model for support surface translations, and the characteristics of the muscle responses were consistent with those of human responses in a previous study. This confirmed the usefulness of our models for simulating human postural control for external forces. Then, postural control simulations for a backward support surface translation were performed with varying degrees of muscle mass, sensory noise and muscle tone [2]. The results confirmed that muscle mass and muscle tone could influence postural control strategies. Human experiments have also confirmed the tendency of muscle tone to influence postural control strategies [3].
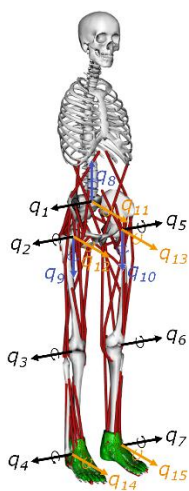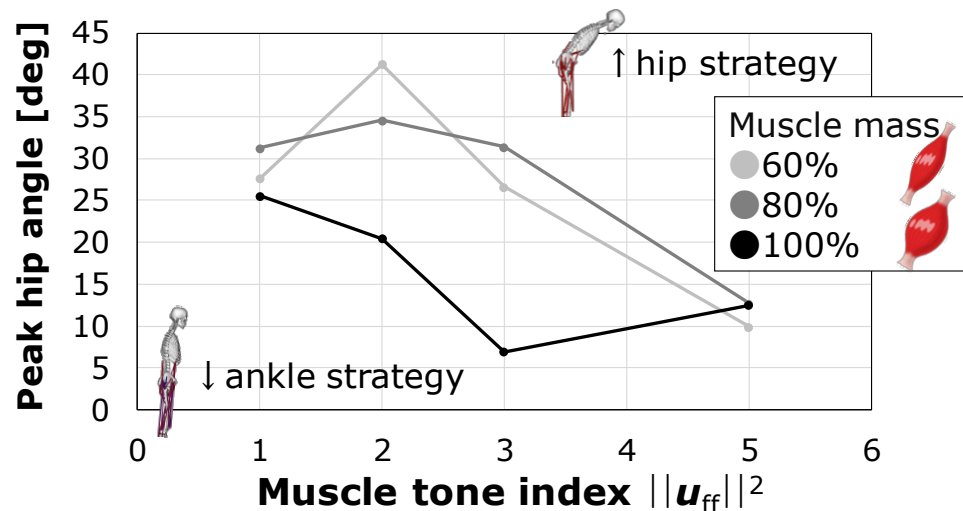

Figure 1. Musculoskeletal model.

Figure 2. The relationship between the muscle tone index ||uff||2 and the postural control strategy index, peak hip angle. When the muscle tone is large, ||uff||2 is large. When the postural control strategy is close to the hip strategy, the peak hip angle is large. The graphs were lower on the right shoulder, resulting in the postural control strategy leaning towards the hip strategy when muscle tone was greater.

Keywords: postural control strategy, musculoskeletal model, forward dynamics simulation

References:
[1] K. Kaminishi, P. Jiang, R. Chiba, K. Takakusaki, and J. Ota, "Postural control of a musculoskeletal model against multidirectional support surface translations," PLoS One, vol. 14, no. 3, p. e0212613, 2019.
[2] K. Kaminishi, R. Chiba, K. Takakusaki, and J. Ota, "Investigation of the effect of tonus on the change in postural control strategy using musculoskeletal simulation," Gait & Posture, vol. 76, pp. 298-304, 2020.

Representation of Postural Abnormalities in Parkinson's Disease Patients Using a Computational Model

Parkinson's disease (PD) is a neurodegenerative disease with postural abnormalities and motor dysfunction. Although there is a concern that the number of patients will increase as the number of elderly increases, the pathological mechanisms have not been fully elucidated. Therefore, as a methodology for understanding the mechanism, we focus on postural abnormalities, which are characteristic of PD, and aim to construct a computer model of postural control in PD. This study aims to represent postural abnormalities on a computer model as an initial step [1].

Our research group proposes a neural system controller model (Fig. 1) that can maintain the musculoskeletal model (Fig. 2) in the upright standing posture (Fig. 3(A)) [2]. The musculoskeletal model is composed of 94 muscles with 17 degrees of freedom, including the neck, which is sufficient for postural abnormalities. The nervous system controller model consists of feedforward control, which outputs the steady muscle activity (muscle tone) required to maintain a standing posture, and feedback control based on sensory input. Using these models, the parameters of a neural postural control model that can maintain standing with an abnormal posture of PD (Fig. 3(B)) as the target posture are calculated by optimization. As a result, the maintenance of a standing position was succeeded even with abnormal posture, and it was confirmed that the posture abnormality could be represented on the computer model. When the abnormal posture was used as the target posture, there was an increase in the value of muscle tone that could be maintained in standing, suggesting that the abnormal posture increased the muscle tone needed to maintain standing.
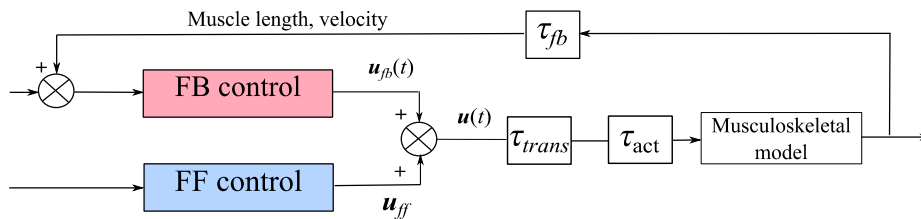

Figure 1. Neural controller model. $\boldsymbol{u}_{fb}(t), \boldsymbol{u}_{ff}, \boldsymbol{u}(\boldsymbol{t})$: feedback, feedforward, and integrated output. $\tau_{fb}, \tau_{trans}, \tau_{act}$: transmission
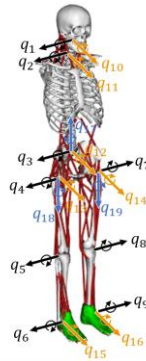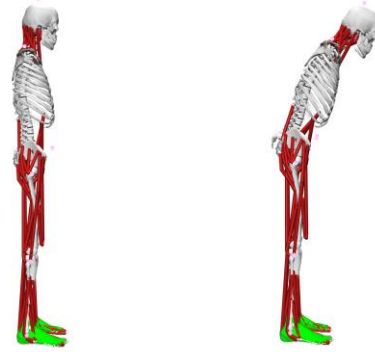
(A) Upright posture   (B) Abnormal posture

Figure 2. Musculoskeletal mode   **Figure 2.** Musculoskeletal mode

Keywords: Parkinson's disease, Posture control model, Abnormal posture

References:

[1] Y. Omura, K. Kaminishi, R. Chiba, K. Takakusaki, and J. Ota, "Representation of Abnormal Posture in Computational Model for Constructing Posture Control Model of Parkinson's Disease", 自律分散システムシンポジウム, Tokyo, Japan, Jan., 25-26, 2020

[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, 2016. 2018; pp. 716–722.

Development of the Wearable Device for Measuring Finger Joint Angle

The measurement of finger movements using wearable devices have the potential to be used in various applications such as human-machine interface (HMI) and rehabilitation. However, wearable measurements using optical fibers and conductive inks, which are currently the mainstream, have the feature that the angle output by the sensor depends on the size and shape of the finger. Therefore, every time the measurer changes, time-consuming calibration is necessary to match the actual joint angle with the sensor output. In case a person with a hand disease cannot perform sufficient calibration, the sensitivity of measurement can be deteriorated and this prevents the measurements with high precision. Therefore, we research aiming to develop a wearable device that can measure the joints angle of fingers without depending on the dimension of the finger.

As a method, the joint angle can be estimated by overlapping the four tendons on the finger at regular intervals and measuring the displacement of them (Fig. 1). By utilizing the difference in the radius of rotation them at the joint part, the joint angle can be measured without depending on the dimension of the finger. By pinching layered belts made of soft polyvinyl chloride (PVC) between the tendons, they bend flexibly even when the fingers have a large curvature, and the intervals between the tendons are kept constant. In order to show the validity of this method, we developed a model miming the motion of flexion and extension of the finger by the serial link mechanism (Fig. 2). An experiment was conducted by placing tendons and belts on the model, and it showed that the proposed method can measure the joint angle with sufficient accuracy. In the next work, we will develop a glove-type device which can measure the finger joint angle based on the proposed method and knowledge obtained from the study so far.
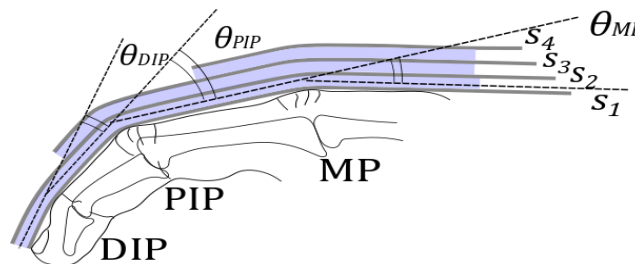

Figure 1. The configuration of tendons and belts on the finger. From the tip of the finger, finger joints are called DIP joint (Distal Interphalangeal joint), PIP joint (Proximal Interphalangeal joint), and MP joint (Metacarpophalangeal joint). From surface of the finger, the first and second threads are tensioned from on the nail, the third tendon is between from the DIP joint and the PIP joint, and the fourth tendon is from between the PIP joint and the MP joint. This configuration enables to measure each joint angle at the same time.
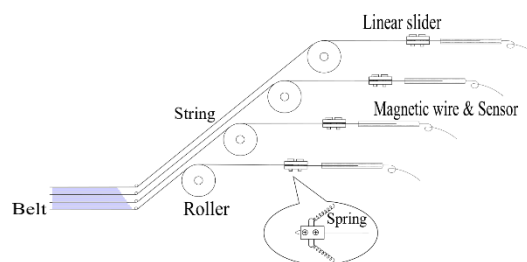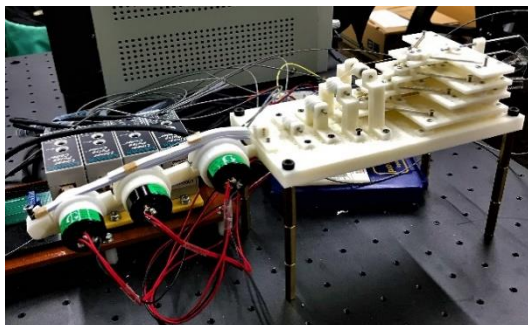

Figure 2. (Left figure) A model of the finger of the serial link mechanism used in the experiment. A potentiometer was incorporated in each joint to measure the ground truth of the joint angle. (Right figure) The pass of the tendons. Each tendon is connected to a linear slider via a roller. The linear slider has a role of connecting the tendon and the magnetic wire, and the displacement of the magnetic wire is measured by a sensor.

Keywords: data glove, wearable device, finger joint angle

Method to Estimate the Muscle Activation Pattern from MRI and EMG

In the study of neuromuscular degenerative disease and in the development of rehabilitation therapies to treat them, monitoring the activity of muscles is crucial to better understand the nature of the impairment and to have a feedback about the changes occurring after applied treatments. As a consequence of pathological conditions, it is also not so uncommon to observe changes occurring in the physical structure and in the behavior of muscles of impaired individuals. It is, therefore, crucial to have a full vision that simultaneously encloses the underlying morphology and the muscle activation behavior, in order to have a full understanding of the impairment status. At the state of the art, the gold standard method to depict morphological information is Magnetic Resonance Imaging (MRI), a diagnostic imaging technique that is used to represent the anatomy and physiological processes happening in the body. For the acquisition of time-related information about the muscle state instead, the most popular technique is electromyography(EMG) is a medical signal acquisition technique that read the potential variation caused by contracting muscles. State of the art method using EMG allow the estimation muscle activity up to motor unit level, but the estimation of deep muscles still remain a challenging problem.

Our group recently proposed a solution to merge the morphology obtained with MRI and the dynamic information from EMG to provide a direct estimation of deep and superficial muscles activities. The method exploits the morphological information contained in the MRI scan to build an electrical lumped model of the conductive volume that is then solved as an inverse problem using the sEMG collected from with a High density EMG electrodes wrapper around the forearm.

We believe that this method can be a valid way to overcome the limitations of the state of the art methods, allowing the estimation of muscle activation with temporal resolution of EMG, potentially improving the information quality for clinicians in the diagnostic process. In particular, we believe that the proposed method can make an important contribution in the field of rehabilitation allowing to track muscle activation pattern on impaired subject during rehabilitative cycles.
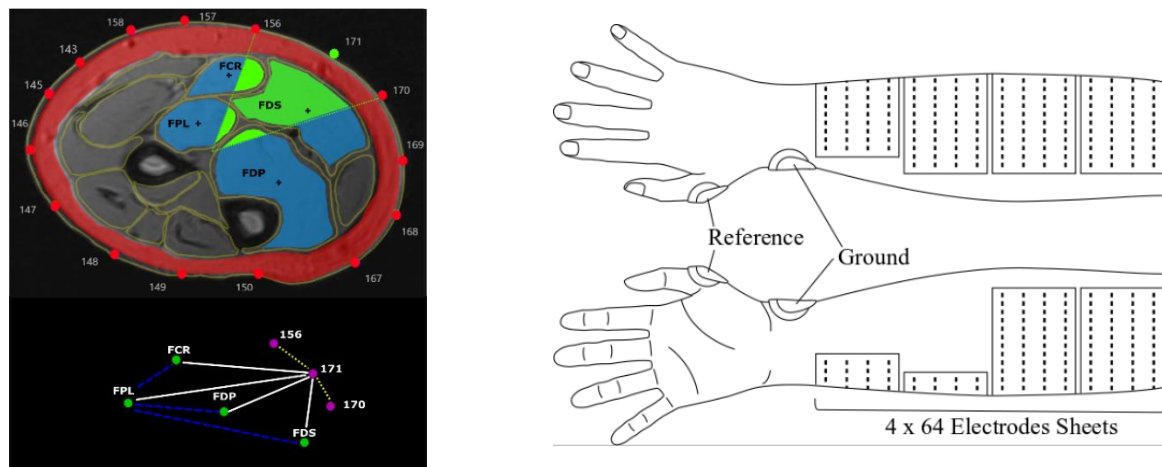

Figure 1. Left : Example of electric circuit construction from the morphological information of the MRI.
Top: positioning of the electrodes on the arm.

Keywords: Neuromuscular control, electromyography, MRI, HD-sEMG, human machine interface

References:
[1] Piovanelli, E., Piovesan, D., Shirafuji, S., & Ota, J. (2019). A Simple Method to Estimate Muscle Currents from HD-sEMG and MRI using Electrical Network and Graph Theory. In 2019 41st Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC) (pp. 2657–2662).
[2] [2] Piovanelli, E., Piovesan, D., Shirafuji, S., & Ota, J. (2019). Estimating Deep Muscles Activation from High Density Surface EMG using Graph Theory. In 2019 IEEE 16th International Conference on Rehabilitation RObotics (ICORR) (pp. 3–8).
[3] [3] Piovanelli, E., Piovesan, D., Shirafuji, S., Su, B., Yoshimura, N., Ogata, Y., & Ota, J. (2020). Towards a simplified estimation of muscle activation pattern from MRI and EMG using electrical network and graph theory. Sensors (Switzerland), 20(3), 1–20.

Learning Patient Transfer Skill by Using a Robot Patient

Nowadays experienced nurses play a vital role at hospitals to take care of seniors and patients. However, many statistics reveal that the learning at schools are inadequate, because the students have few accessibilities to obtain the practical experience from actual patients. With the progress of robotic technology, many robot patients were proposed for educational purposes. Most systems can only reproduce single type of patient which cause inefficiency to learn variability of patient. In Ref [1], we develop a robot patient simulating two types of patient for the nursing student to learn patient transfer skill, and also evaluate the learning effectiveness. Patient transfer is adopted because of its difficulty in interaction between nurse and patient. Two types of patients - injured arm with painful sensation and expression, and hemiplegia - were selected as target patients. One is related to the painful sensation from the injuries; and the other is related to the behavioral problems. A robot patient system was developed to observe the learning effectiveness on the nursing students. An evaluation method of checklist is proposed by nursing teachers. An experiment comprised by pre-test, practice, and post-test was conducted by nursing students. The experimental trails at pre- and post- tests are evaluated and the effectiveness of the proposed system is shown. In Ref. [2], we propose a method to evaluate the nurse's transfer skill from the sensor information embedded in the patient, which can be used for designing a new robotic patient.
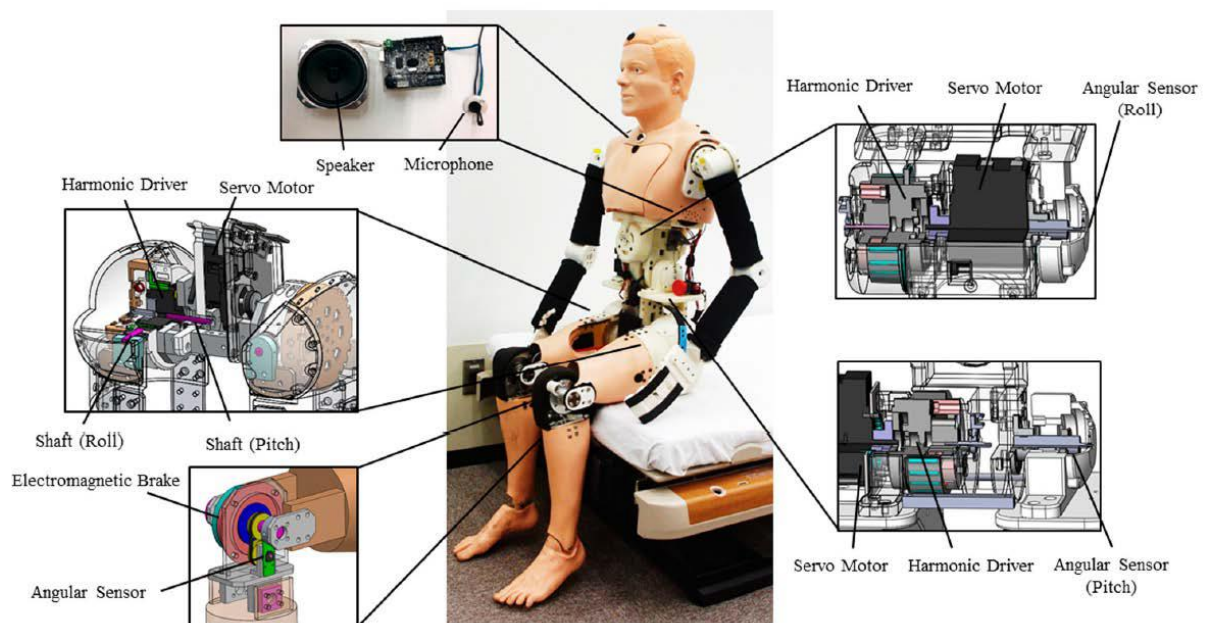

Figure 1. Configuration and mechanism of the robot patient

References:
[1] Lin,Chingszu, Huang,Zhifeng, Kanai-Pak,Masako, Maeda,Jukai, Kitajima,Yasuko,Nakamura,Mitsuhiro, Kuwahara,Noriaki, Ogata,Taiki, & Ota,Jun. (2019). Effect of practice on similarand dissimilar skills in patient transfer through training with a robot patient. Advanced Robotics, 33(6), 278-292. doi: 10.1080/01691864.2019.1578689.
[2] Lin,Chingszu, Ogata,Taiki, Kanai-Pak,Masako, Maeda,Jukai, Kitajima,Yasuko, Nakamura,Mitsuhiro, Kuwahara,Noriaki & Ota,Jun. (2018). Translational acceleration, rotational speed, and joint angle of patients related to correct/incorrect methods of transfer skills by nurses. Sensors, 18(9), 2975, 1-28. doi:10.3390/s18092975.

Multi-attention Deep Recurrent Neural Network for Nursing Action Evaluation Using Wearable Sensor

Today, there is an increasing demand of qualified and skillful nurses in our society due to the problems as aging population and so on. However, the shortage of nursing educators and high student-educator ratio at nursing school result that nursing student cannot receive enough individualized supervision and feedback when they are training nursing skills. Thus, a nursing action evaluation system that can assess the performance of students when practicing specific nursing actions becomes an urgent need. Such an evaluation system should be designed with less hand-crafted procedures for its extensibility. Additionally, realizing high accuracy of nursing action recognition, especially fine-grained action recognition remains a problem. This reflects in the recognition of the correct and incorrect methods when students perform a nursing action.

To satisfy above requirements, we propose a multi-attention deep recurrent neural network (MA-DRNN) for nursing action recognition, by applying the attention mechanism to RNN-based architecture. To validate the effectiveness of the proposed method, we select two critical nursing actions as standing-up and turning-around of a nursing skill called patient transfer as target actions. In order to train and test the model, data samples of correct and incorrect methods for performing these target actions are collected by attaching 6 inertial measurement unit sensors on patient's body (see Fig.1). The experimental results demonstrate that the proposed model outperforms the state-of-the-art wearable sensor based methods and achieves approximately 96% recognition accuracy.
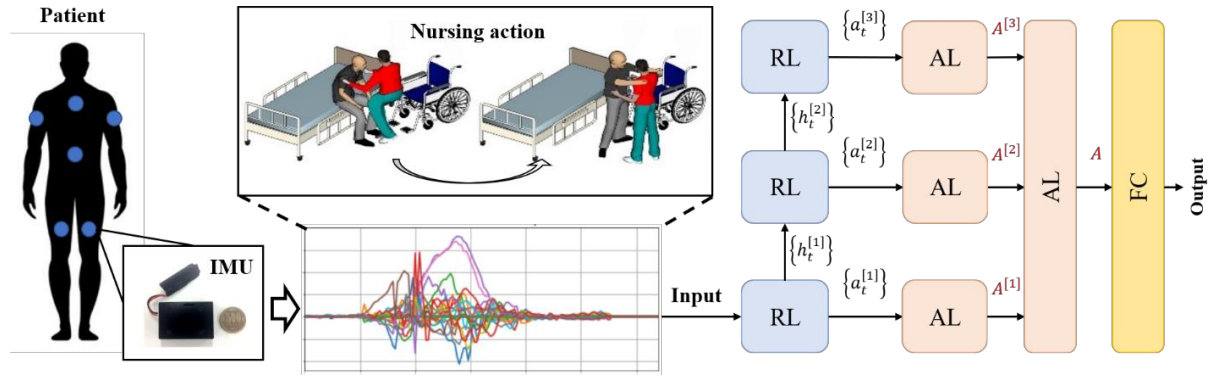

Figure 1. Nursing action evaluation: There are 6 IMU sensors attached on different parts of patient's body. As for recognition model MA-DRNN, RL refers to recurrent layer, AL refers to attention layer and FC refers to fully connection layer.

Keywords: nursing skill evaluation, fine-grained action recognition, recurrent neural network, attention mechanism

References:
[1] Zhong, Z., Lin, C., Ogata, T., & Ota, J. (2020, March). Multi-attention deep recurrent neural network for nursing action evaluation using wearable sensor. In Proceedings of the 25th International Conference on Intelligent User Interfaces (pp. 546-550).

Service Ecosystem Design using Social Modeling to Incorporate Customers' Behavioral Logic

The Customer dysfunctional behaviors affect service providers' workloads. However, few studies on service ecosystem design have investigated how to prevent these behaviors. This study thus proposes a service ecosystem design tool that can analyze how dysfunctional behaviors affect other actors in the service ecosystem. To this end, customers' behavioral logic is incorporated into social modeling to analyze their dysfunctional behaviors. This study also uses goal-oriented requirement language as design and analysis tools. Then, structural equation modeling is used to analyze the effects of behavioral logics. A case study of a home delivery service demonstrates the applicability of this methodology to analyze the effects of customer behavioral logics on service ecosystem actors. The service design method developed in this study contributes to decreasing the probability of customer dysfunctional behavior, which can also reduce service providers' workload.
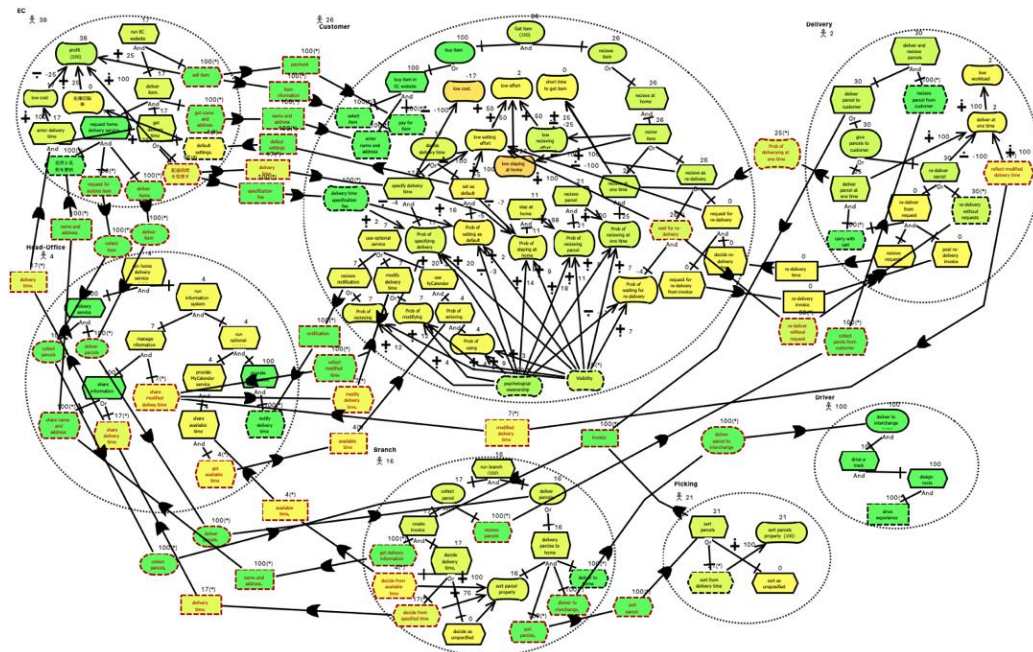
Figure 1. Analysis results about the effects of behavioral logics on each actor's goal by GRL.

Keywords: Service Design, Service Ecosystem, Behavioral Logic, Dysfunctional Customer Behavior

References:
[1] Masafumi Hamano, Bach Q. Ho, Tatsunori Hara, Jun Ota: Service Ecosystem Design Using Social Modeling to Incorporate Customers' Behavioral Logic, Serviceology for Services (7th International Conference, ICServ 2020), T. Takenaka et al (Eds.), CCIS 1189, pp.217-234, Springer, 2020

[2] 濱野雅史, ホーバック, 原辰徳, 太田順:宅配サービスの利便性が顧客心理と行動にもたらす影響の分析, サービス学会第 7 回国内大会予稿集, B-12-04, 2019.

[3] Bach Q. Ho, Yuna Murae, Tatsunori Hara and Yukihiko Okada: Consumer Experience as Suppliers on Value Co-Creation Behavior. Journal of Serviceology, Vol.4, No.1, pp.1-7, 2019.

[4] Yuna Murae, Bach Q. Ho, Tatsunori Hara, Yukihiko Okada: Two Aspects of Customer Participation Behaviors and the Different Effects in Service Delivery: Evidence from Home Delivery Services. Journal of Marketing Development and Competitiveness, Journal of Marketing Development and Competitiveness, Vol.13, No.1, pp.45-58, 2019.