Introduction to the Mobile Robotics Lab (OTA Lab) 2021

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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
- Measurement pose optimization in robot calibration using a hand-eye camera
- 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

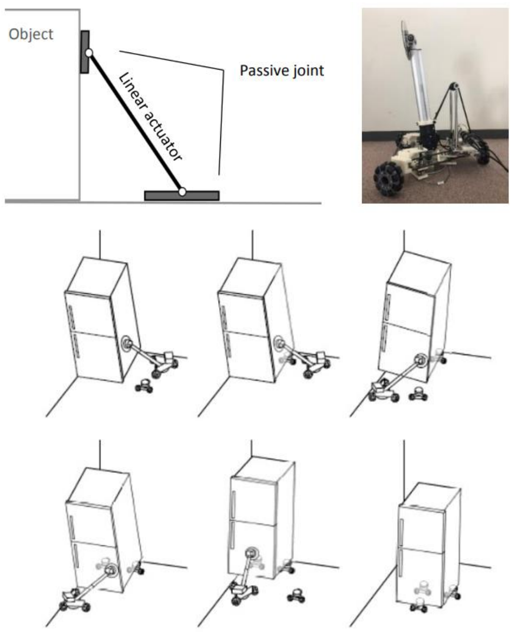
- Musculoskeletal simulation of human stance postural control for external forces
- Modeling human postural control by neural controller considering the vestibulospinal tract
- Proposal of a neuromusculoskeletal model considering muscle tone in human gait
- Development of the wearable device for measuring finger joint angle
- Method to estimate the muscle activation pattern from MRI and EMG
- Learning patient transfer skill by using a robot patient
- User State Estimation Using Smartphones

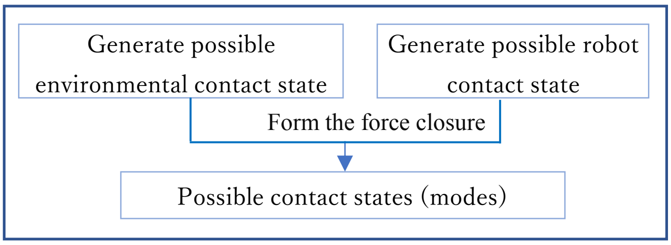
Development and Manipulation Planning of Small Mobile Robot

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.





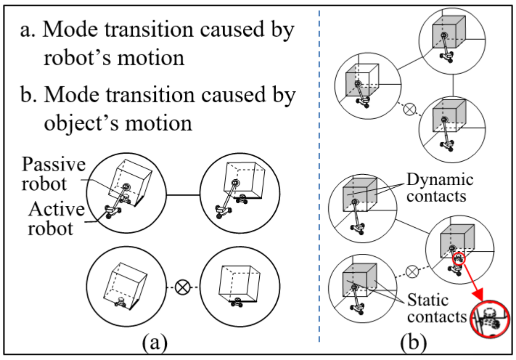


Figure 1. Constraints of the joints on the robotics leg using wires and non-circular pulleys.

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.

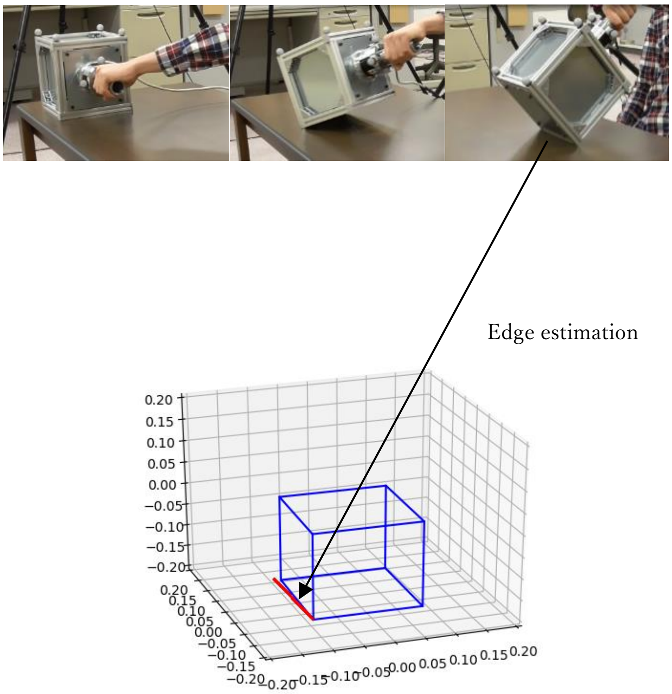


Figure 1. Experiment and result

Keywords: contact state estimation, compliant motion, manipulation

References:

[1] Seiya Ishikawa, Shouhei Shirafuji, and Jun Ota: "Objective Functions of Principal Contact Estimation from Motion Based on the Geometrical Singular Condition," Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems, Las Vegas, NV, USA (Virtual), pp.9465-9471, October, 2020.

[2] 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

Measurement Pose Optimization in Robot Calibration Using a Hand-eye Camera

A kinematic model for controlling a robot is constructed based on kinematic parameters such as link length and joint offset. However, the kinematic parameters are subject to errors due to factors such as variations in robot processing and assembly and thermal expansion. Therefore, correction of the kinematic parameters, i.e., robot calibration, is necessary. In recent years, however, the use of hand-eye cameras has been attracting attention for its simplicity. However, the measurement accuracy of the camera is relatively low, and the calibration accuracy also decreases. In other words, there is a trade-off between the ease and accuracy of camera measurement.

On the other hand, it has been reported that the accuracy of robot calibration depends on the measurement pose, i.e., it depends on what pose the robot is placed in for measurement. In this regard, there is a study that optimizes the measurement pose under a certain constraint by sensitivity analysis of the relationship between the measurement pose and kinematic parameters. However, this method cannot be applied to robot calibration using a hand-eye camera, because the hand-eye camera must be able to capture the calibration marker, and the constraints of the robot hand change depending on the location of the marker.

In order to achieve high accuracy in robot calibration using a hand-eye camera, we propose a method for optimizing the measurement pose considering the constraints imposed by the hand-eye camera. The approach of the proposed method is to optimize the location of the marker and the measurement pose of the robot to minimize the estimation error of the kinematic parameters under the constraint that the relative pose between the camera and the marker is fixed.

As a result of the simulation verification, the optimized measurement pose was obtained as shown in Fig. 1, and the improvement of calibration accuracy was confirmed. In the future, we aim to further improve the accuracy by optimizing the relative pose between the camera and the marker.

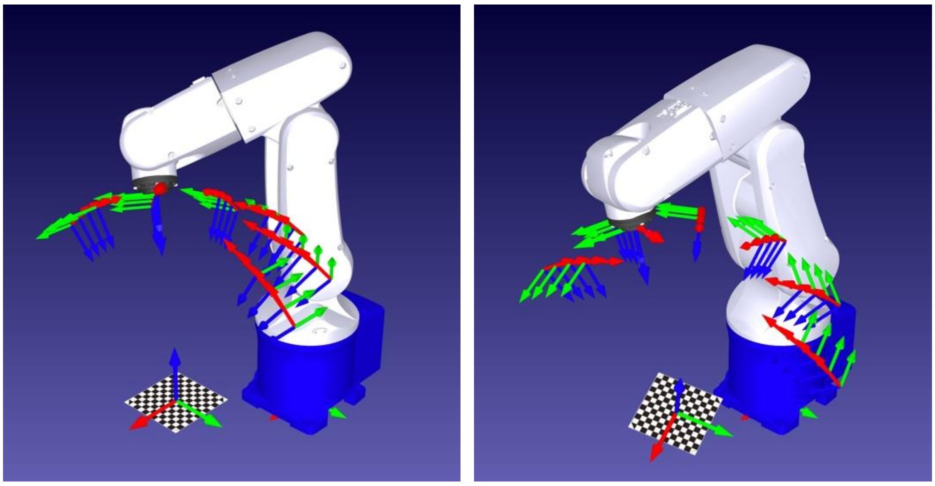


Fig.1 (Left) Initial measurement pose. (Right) Optimized measurement pose.

Keywords: robot calibration, optimization, hand-eye camera, absolute positioning accuracy

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.

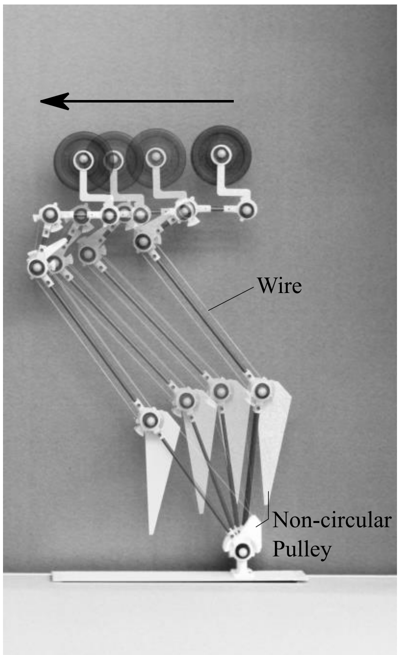


Figure 1. Constraints of the joints on the robotics leg using wires and non-circular pulleys.

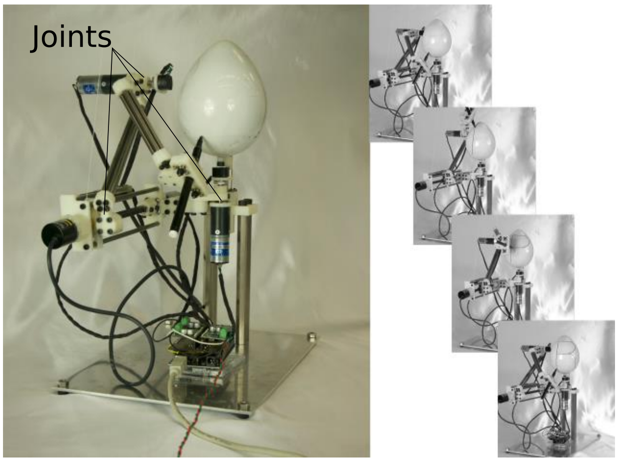


Figure 2. Mechanism to draw a letter on an egg-shaped object with less numbers of joints.

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 as shown in Fig. 1. In the algorithm, a queue module-based throughput calculation approach is proposed to evaluate the effectiveness of the buffer design solution efficiently. Numerical examples such as shown in Fig. 2 indicate that the proposed algorithm is applicable to design buffers for warehouse systems efficiently (Refs. [1], [2], and [3]). In the future, we will improve the proposed buffer design approach and make it more applicable to very large-scale warehouse systems.

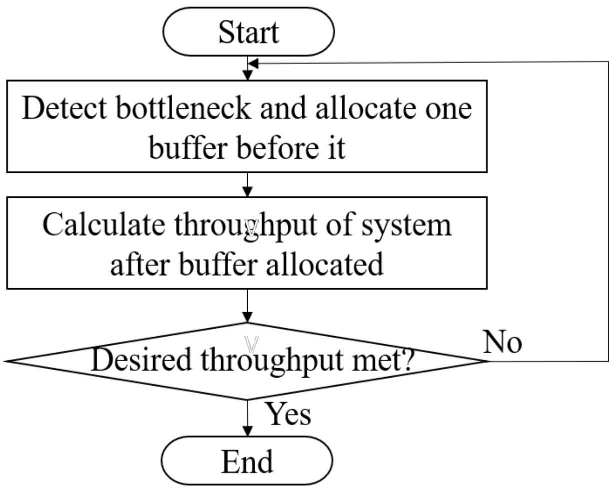


Fig.1 Framework of the proposed algorithm

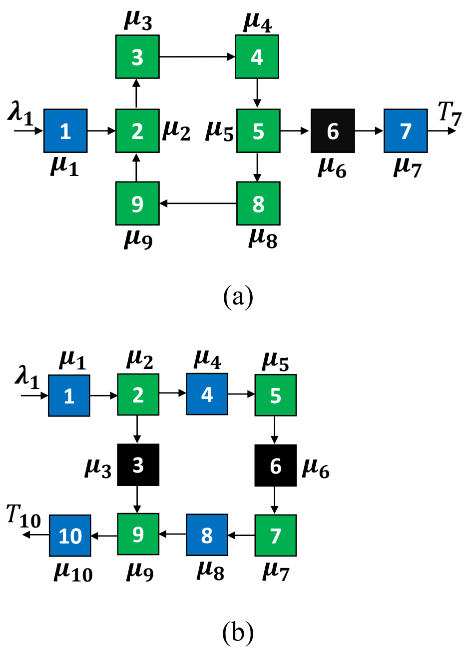


Fig.2 Examples of the problem to solve

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

References:

[1] Gao,Sixiao, Higashi,Toshimitsu, Kobayashi,Toyokazu, Taneda,Kosuke, & Ota,Jun. (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.

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[3] Gao,Sixiao, Higashi,Toshimitsu, Kobayashi,Toyokazu, Taneda,Kosuke, Rubrico,Jose,I.U., & Ota,Jun. (2020). Buffer allocation via bottleneck-based variable neighborhood search. Applied Sciences, 10(23), 8569, 1-22. doi:10.3390/app10238569.

Musculoskeletal Simulation of Human Standing Posture Control for External Forces

Humans use movements of the ankles and hips to maintain balance when subjected to external forces. We are investigating the mechanism of this control by constructing a neural controller model for the control of standing posture based on physiological findings. We have proposed a neural controller model that can maintain the standing posture of a musculoskeletal model even when external forces are applied in various directions [1]. Using this neural controller model, we are investigating various responses to external forces. For example, the relationship between muscle tone and postural control strategies was investigated in [2]. Here, it was shown that the greater the muscle tone, the more likely it was that the standing posture was maintained mainly by ankle movements rather than hip movements.

What we are now focusing on is the movement of the arms when an external force is applied and the body sways. Arms are moved for various purposes, such as swinging for balance, grasping handrails, and protecting the head. Therefore, it is difficult to isolate the purpose of the arm movements observed experimentally. In our musculoskeletal simulation, it is easy to isolate such purposes, which is useful for studying arm movements. Fig. 1 shows the movements of the center of gravity when the musculoskeletal models with and without arms are made to stand and an external force is applied [3]. Although the arms themselves were not controlled here, it was shown that the swaying of the body was reduced by the presence of the arms. This shows the importance of the role of the arms in maintaining a standing posture.

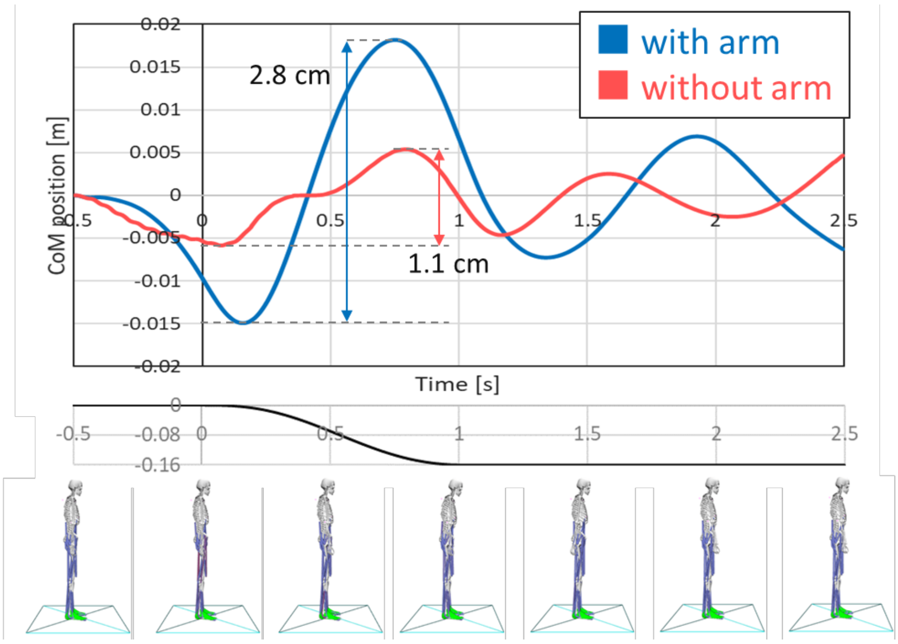


Figure 1. Movements of the center of gravity in the front-back direction when an external force is applied to a musculoskeletal model with and without arms.

Keywords: mental health care, smartphone, machine learning

References

[1] K. Kaminishi, P. Jiang, R. Chiba, K. Takakusaki, & J. Ota. (2019). Postural control of a musculoskeletal model against multidirectional support surface translations. PLoS ONE, 14.(3): e0212613. doi: 10.1371/journal.pone.0212613.

[2] K. Kaminishi, R. Chiba, K. Takakusaki, & J. Ota. (2020). Investigation of the effect of tonus on the change in postural control strategy using musculoskeletal simulation. Gait & Posture, 76, 298-304, doi: 10.1016/j.gaitpost.2019.12.015.

[3] K. Kaminishi, R. Chiba, K. Takakusaki, & J. Ota. (2020). Musculoskeletal simulations to understand the role of arms in maintaining standing posture for external forces, Proceedings of the 38th Annual Conference of the Robotics Society of Japan, RSJ2020AC1H3-04, (pp. 1-2), Online, October 9-11 (in Japanese).

Modeling Human Postural Control by Neural Controller Considering the Vestibulospinal Tract

Humans control their posture in their daily lives. When postural control is impaired by neurological diseases, their lives are restricted. It is essential to understand the postural control mechanism to reduce this restriction. The neural pathways play important roles in postural control. These neural pathways are the reticulospinal tract (RST) which controls stiffness (muscle tone), and the vestibulospinal tract (VST) which keeps their posture upright. However, the role of these neural pathways in human postural control has not been verified in detail. Therefore, we aim to verify the mechanism of human postural control by constructing a computational model focusing on these neural pathways.

We construct a computational model consisting of a musculoskeletal model with 17 degrees of freedom and 94 muscles and a neural controller model with controls based on the VST and RST. The validity of the computational model was verified by comparing simulation results to experimental results with human subjects. Afterward, the role of the VST was verified by the simulation results. As a result, it was verified that control based on the VST enabled the musculoskeletal model to stand with lower muscle tone. In the absence of control based on the VST, an increase in postural sway was observed. This result suggests that the function of the VST is important for human to stand with low muscle tone [1].

Keywords: Posture control, Vestibulospinal tract, Muscle tone

References

[1] 尾村 優一郎，上西 康平，千葉 龍介，高草木 薫，太田 順，“前庭脊髄路を考慮した神経系コントローラによるヒトの姿勢制御のモデル化”，第 33 回自律分散システム・シンポジウム，オンライン，2021 年 3 月

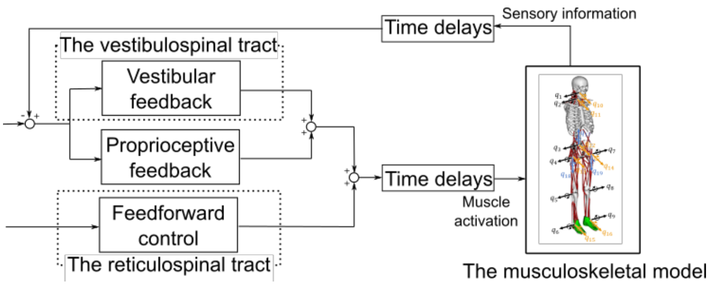


Figure 1. Computational model. The red shaded area denotes the control based on the VST and FF control denotes the control based on the RST. $\boldsymbol{K}_{ves}, \boldsymbol{K}_p, \boldsymbol{K}_d$ are FB gains correspond to head kinetic information, muscle length velocity, muscle length. $\boldsymbol{u}_{fb}(t), \boldsymbol{u}_{ff}$ are FB・FF outputs. $\tau_{fb}, \tau_{trans}, \tau_{act}$ are the time delays of transmission, FB, activation dynamics.

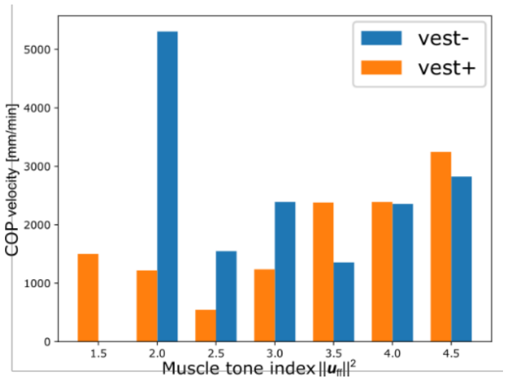


Figure 2. COP velocity. The blue bar denotes COP velocity without VST. The orange bar denotes COP velocity with VST.

Proposal of a Neuromusculoskeletal Model Considering Muscle Tone in Human Gait

In an aging society, it is increasingly important to solve problems related to human gait. One of these issues is the relationship between gait and muscle tone. In this study, we propose a neuromusculoskeletal model that can be used to represent and evaluate the movement changes generated by changes in muscle tone in human gait using computational simulations. The model is based using a musculoskeletal model with 70 muscles and a neurological controller model that can represent muscle tone. As a hypothesis to judge the validity of the model, a high muscle tone makes it difficult to maintain gait and makes the stride length narrow.

A total of 1470 parameters were optimized for 3 days for each trial with varying muscle tone. As a result under the condition of high muscle tone, the gait maintenance time became shorter, and the stride length became narrow compared with the experimental value. Therefore, the hypothesis used to judge the validity of the model that gait maintenance becomes difficult and stride length becomes narrow under high muscle tone was proved. In addition, the tendency for changes in the angle of the knee joint, the distance traveled by the center of the foot pressure, the number of times the foot touched the ground, the distance the foot swung forward, the regularity and periodicity of each gait, and the bimodality of foot pressure were evaluated and confirmed to be natural. From these results, we conclude that the neuromusculoskeletal model for gait proposed in this study was appropriate.

In the future, we will extend the mathematical model for start walking between standing and gait, and propose a mathematical model that can verify standing, gait, and start walking seamlessly.

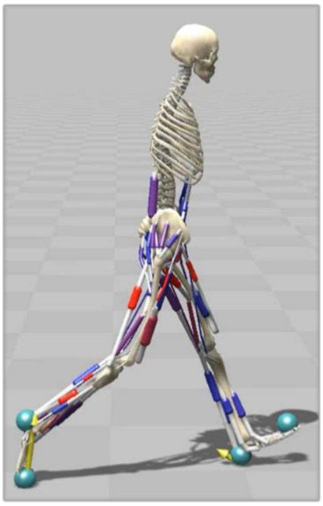


Figure 1. Musculoskeletal Model.

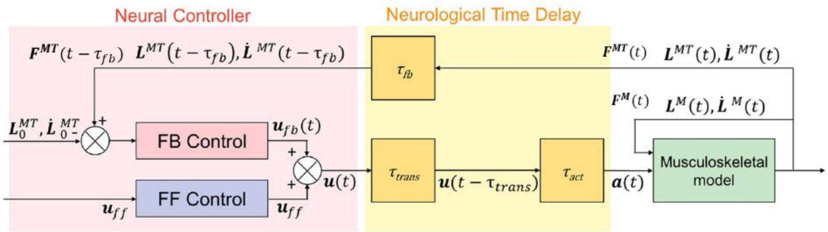


Figure 2. Neuroystem Controller Model.

Muscle Tension	Walking Maintenance Time(s)	Pace(m)
1	5.00	0.648
5	5.00	0.806
10	4.94	0.514
20	1.30	

Figure 3. Results of computational simulation of gait..

Keywords: Gait control, musculoskeletal model, nerurosystem controller, forward dynamics simulation, SCONE

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.

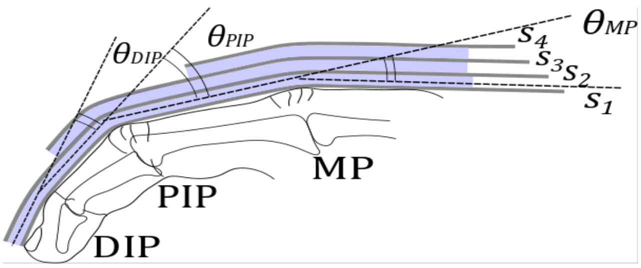
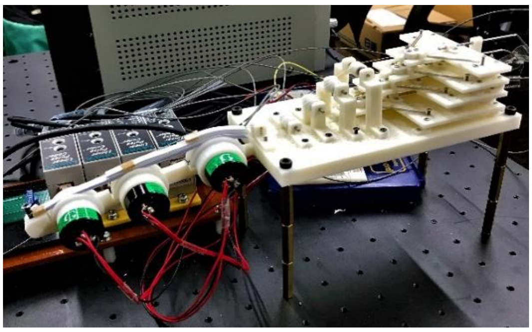


Figure 1. The configuration of tendons and belts on the finger. From the tip of the finger, finger joints are called DIP joint (Distal Interphalangeal joint), PIP joint (Proximal Interphalangeal joint), and MP joint (Metacarpophalangeal joint). From surface of the finger, the first and second threads 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.



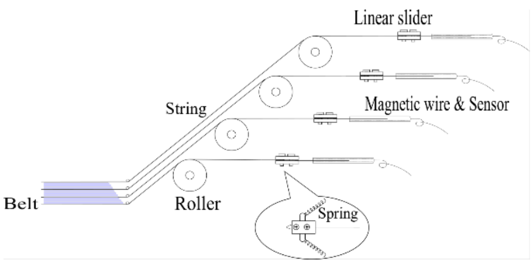


Figure 2. (Left figure) A model of the finger of the serial link mechanism used in the experiment. A potentiometer was incorporated in each joint to measure the ground truth of the joint angle. (Right figure) The pass of the tendons. Each tendon is connected to a linear slider via a roller. The linear 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.

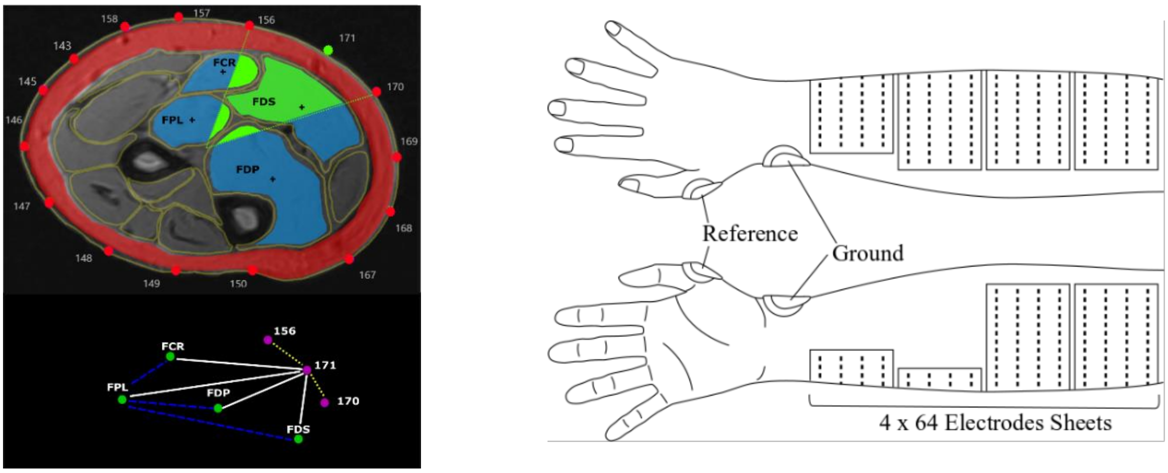


Figure 1. Left : Example of electric circuit construction from the morphological information of the MRI. Top: positioning of the electrodes on the arm.

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).

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Learning Patient Transfer Skill by Using a Robot Patient

In recent years, there has been an increasing need to develop training tools for nurses to learn nursing movements. In this research project, we aim to develop a robot patient that can be used for education to nurses with physical load. By using the information obtained from the robot, we aim to create a system that can automatically distinguish the appropriate and inappropriate movements in the transfer process for nursing students. In Ref. [1], we verified whether there is any difference between the wheelchair transfer movements performed by a nurse acting on a robot patient and those performed on a real human patient. The translational acceleration of the robot waist, the rotational velocity of the chest, and the joint angles of the shoulders, hips, and knees were set as the kinematic information obtained from the robot, and an inertial measurement unit (IMU) and an angular sensor were attached to the robot patient to measure these parameters. The results showed that the simulated patient and the robotic patient could achieve the same effect in most of the transfer processes, indicating that the robotic patient is a suitable substitute for the real human patient. In Ref. [2], we developed a robot that have a lower limb consisting of active joints including compliant units. We also propose a control method for a robot patient that reproduces the patient's movements for nursing care where the nurse assists the patient in changing from a sit to a stand posture. We found that the torque applied to the robot and the torque generated by the robot are different when the nurse performs the correct motion and the wrong motion. The results showed that the robot could be used as a learning system for wheelchair transfer.

Keywords: robot patient, nursing education, mechanical design

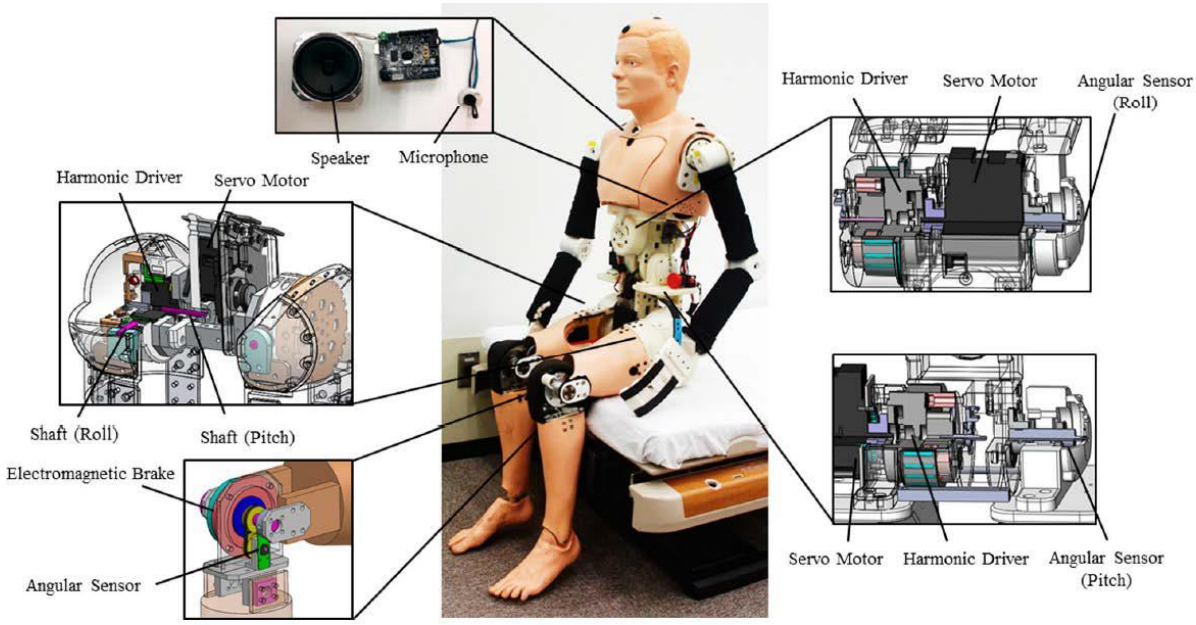

Fig.1 Details of the robot patient

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User State Estimation Using Smartphones

Interest in mental health care has been increasing in recent years, as stress checks have become mandatory. Questionnaires have been widely used to understand people's states. However, taking questionnaires frequently is cumbersome and burdensome. Therefore, we aim to estimate the user's state based on the usage patterns of smartphones, which we use on a daily basis. Smartphones are equipped with a variety of sensors, which are useful as passive sensing tools. It also goes without saying that smartphones are very widespread. By realizing this estimation, it is expected to encourage people's self-care and to monitor their daily mental health.

An example of the estimation process is shown in Fig. 1. Participants in the experiment answer questionnaires regularly, and at the same time, data on their smartphone usage is recorded. The data is labeled according to changes in the questionnaire score. From the smartphone logs, daily and weekly feature values are calculated. Based on these labels and features, supervised learning is performed to create a model that estimates the variation in survey scores from smartphone logs.

So far, we have succeeded in estimating the score variations of questionnaires related to QOL and well-being, such as The Positive and Negative Affect Scales, Flourishing Scale, and The Subjective Well-being Inventory [1]. In particular, for users who frequently use smartphones, the model was able to estimate with an accuracy of over 80% whether the questionnaire scores increased or decreased compared to one week ago. We also constructed an estimation model for LF/HF, which is a heart rate variability index related to stress, instead of questionnaires [2].

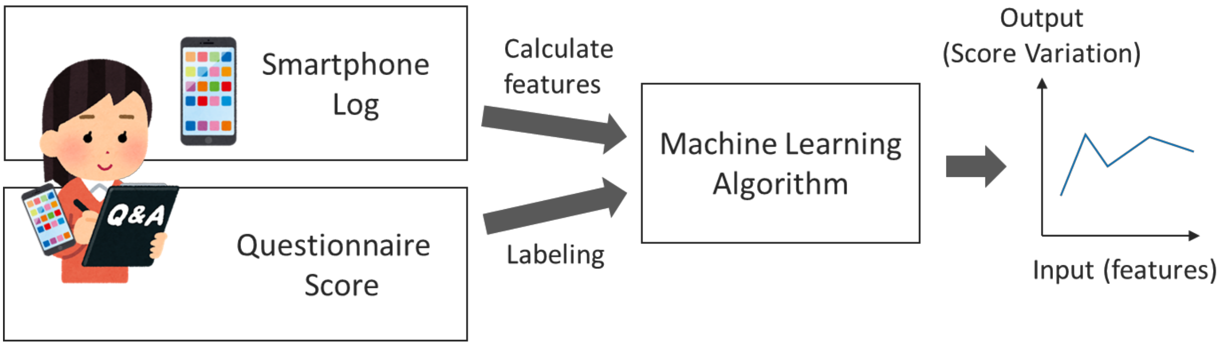

Figure 1. Process for estimating user states from smartphone logs.

Keywords: mental health care, smartphone, machine learning

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