2023 45th Annual International Conference of the IEEE Engineering in Medicine & Biology Society (EMBC) | 979-8-3503-2447-1/23/$31.00 ©2023 IEEE | DOI: 10.1109/EMBC40787.2023.10340879

A Simple Simulation System for Quantifying Buttock Loads Caused by Daily Activities of Wheelchair Users

Kunihiro Ogata[1], Kosuke Takano[2], Nobuto Matsuhira[2], Tsuyoshi Nakayama[3]

Abstract— **The purpose of this study is to quantify the load generated on the buttocks during wheelchair operation in order to clarify the cause of pressure injuries on the buttocks of wheelchair users. In the case of repeated measurements, pressure injuries may occur by conducting experiments with people with actual disabilities. In this study, we proposed a method of dynamic simulation using a humanoid model in order to carry out buttock load safely due to exercise. In addition, the load on the buttocks is quantified by reproducing a simulated cushion that reproduces the actual physical properties on the simulator. When we conducted an evaluation experiment of the developed simulation to quantify the buttock load, we confirmed the validity of this simulator in the front-back direction. On the other hand, the correlation with the actual data is low in the left-right direction, and it is considered necessary to improve the humanoid model in order to improve the accuracy.**

I. INTRODUCTION

Most people with spinal cord injuries require the use of a manual or electric wheelchair to move. Therefore, by assisting them to lead a self-reliant life, we can encourage their social participation. Some individuals with spinal cord injury use manual or electricpowered wheelchairs to move and they spend many hours a day sitting on the wheelchair. Therefore, individuals with spinal cord injury are at risk of developing pressure sores. The National Pressure Injury Advisory Panel (NPIAP) defined an occurrence mechanism of the pressure injury as "A pressure injury is localized damage to the skin and underlying soft tissue usually over a bony prominence or related to a medical or other device. The injury can present as intact skin or an open injury and may be painful. The injury occurs as a result of intense and/or prolonged pressure or pressure in combination with shear. The tolerance of soft tissue for pressure and shear may also be affected by microclimate, nutrition, perfusion, co-morbidities and condition of the soft tissue [1]." Since wheelchair users spend most of the day in a sitting posture, the buttocks are subjected to continuous stress, and pressure injuries are often formed on the buttocks. In addition to the pressure on the buttocks, it has been suggested that the shear force generated during movement is a significant cause of pressure injuries in wheelchair users [2]. There are several reports on the measurement of the pressure and displacement force acting on the buttocks [3][4]. Although these studies only measure the shear force of the buttocks in a static state, various behaviors such as movement and eating are indispensable in daily life. Such movements can dynamically change the load on the buttocks. By measuring and quantifying them, it is considered that the risk of pressure injury development can be evaluated in more detail.

[1]Human Augmentation Research Center, National Institute of Advanced Industrial Science and Technology (AIST), 6-2-3 Kashiwa-no-ha, Kashiwa-shi, Chiba, Japan ogata.kunihiro@aist.go.jp

[2]Department of Engineering Science and Mechanics, Shibaura Institute of Technology, 3-7-5, Toyosu, Koto-ku, Tokyo, Japan md20050, matsuhir@shibaura-it.ac.jp

[3]Research Institute, National Rehabilitation Center for Persons with Disabilities, 4-1 Namiki, Tokorozawa, Saitama, Japan nakayama-tsuyoshi@rehab.go. jp

II. PURPOSE AND PREVIOUS STUDIES

Studies on the relationship between pressure injuries and external forces include the relationship between pressure injury risk and pressure [5], and the measurement of pressure and shear forces on the buttocks [6] etc. have been reported. In addition, the effects of the type of cushion used on the wheelchair and the posture of the upper limbs on the pressure and blood flow at the ischial nodule have been investigated. However, these reported cases remain stationary, and the load survey for wheelchair users' rowing movements has not been conducted. In addition, several methods for calculating the stress of the 3D buttock model using the finite element method(FEM) have been reported [7].

Therefore, in this study, we aim to evaluate the risk of pressure injuries due to activities of daily living by quantifying the buttock load during movement of wheelchair users. We will develop a simple simulator that can quantify the buttock load during movement by dynamic simulation even if it is only body movement. By using this simulator, we aim to elucidate the causal relationship between the load generated in the buttocks during wheelchair movement and body movement.

III. SIMULATION SYSTEM

When conducting experiments on actual persons with disabilities, there is a possibility that pressure injuries will be uttered by repeated experiments. In addition, it is difficult to accurately evaluate motion data of non-disabled people because the movements of non-wheelchair users differ greatly from those of wheelchair users. Therefore, we have developed a simple simulator that can quantify the buttock load in wheelchair rowing motion using dynamics simulation.

Figure 1 shows an overview of the simulation system. The humanoid model can adjust each joint to any posture. The posture input data to the simulator is obtained from the actual human movement. An inertial motion capture system is used to acquire attitude information. This is by attaching the IMU [8] to each part of the body. The joint angle of the whole body can be estimated based on the mechanistic calculation. The humanoid model simulates the load on the

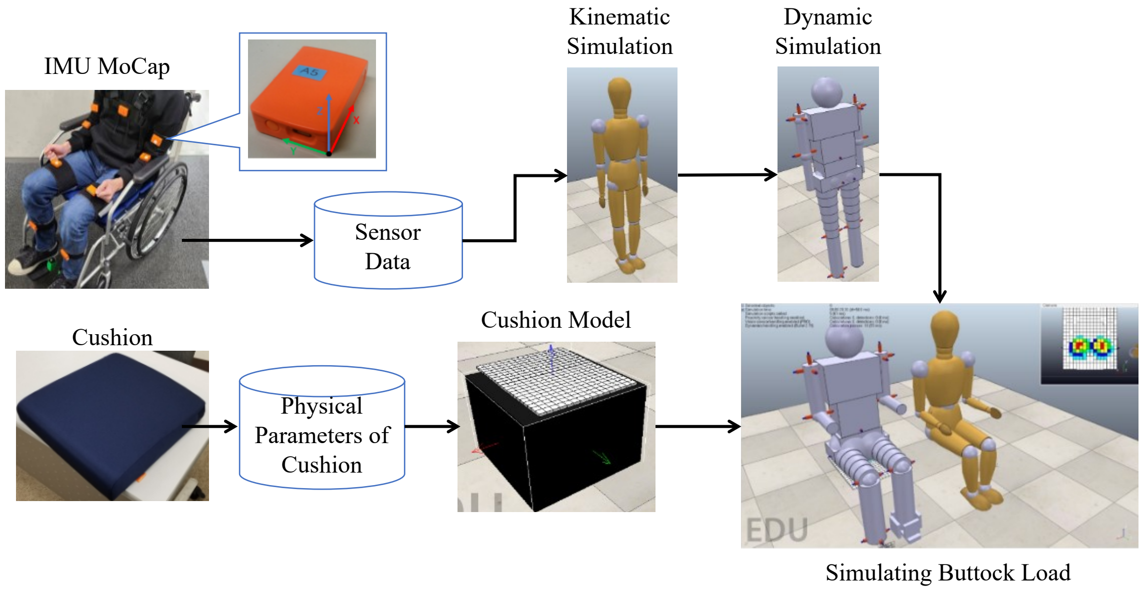


Fig. 1. A dynamics simulation system to easily evaluate the developed pressure injury risk.

buttocks by sitting on the chair model. CoppeliaSim was used for these dynamics simulations. By sending data from the IMU to CoppeliaSim via socket communication, it is possible to visualize the posture of a person in real time on the simulator.

A. *CoppeliaSim*

CoppeliaSim(formerly known as V-REP) is a robot simulator with an integrated environment based on a distributed architecture [9]. Various robots and sensors are prepared in the simulator, and by combining them, it is possible to perform robot simulations in an environment suitable for the user. Moreover, the control of the robot and the sensor, etc. is possible by describing it with the Lua language in the script in CoppeliaSim, and by using Remote API, which is an extension function of CoppeliaSim, the exchange of data through the socket communication is also possible by the language other than Lua. The previous study was used to measure the load between the cushion and the buttocks during seating [10].

B. *Simulation Model*

In CoppeliaSim, there are two types of models: dynamics model and non-dynamics model(kinematic model). The dynamics model takes into account the contact with other models and mass, and enables falling, collision, and bouncing. On the other hand, non-dynamical models do not consider mass or contact, and cannot be used for falling or collision, but can be used to control position and posture. For the dynamics model, there is a joint called Revolute Joint that controls the rotation around one axis. This enables the non-dynamics model to output the accurate body motion and the dynamics model to output the load between the buttocks and the seat (cushion).

Figure 1 shows these models. The length and weight of the body can be changed by the subjects. The shape of the buttocks and thighs in the dynamics model has a significant effect on the pressure distribution between the seat surfaces. In this study, the buttocks were considered as a sphere and the thighs as a cylinder, and they were combined to form a simplified model.

The shape of the buttocks of the simulator is important for quantifying the load on the buttocks in the sitting position. Kumar et al. have proposed a method of modeling the buttocks and thighs with hemispheres and cylinders. Based on this, Ogata et al. have developed a soft buttock dummy and evaluated the risk of pressure injuries. In this study as well, we decided to model the buttocks with hemispheres and cylinders as in these previous studies. The model of the buttocks and thighs prepared is shown in Fig. 2 The thigh is not a simple cylinder, but is tapered from the hip joint to the knee joint.

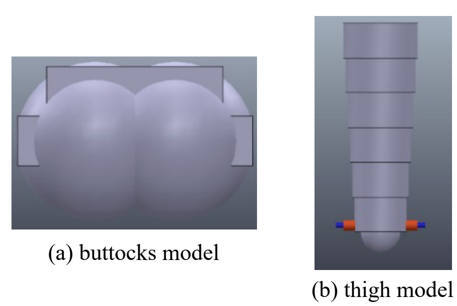


Fig. 2. The shape of the buttocks and thighs of a humanoid model of dynamics simulation.

Figure 1 shows the model of the seat surface in contact with the buttocks. Since wheelchair users often use cushions for their buttocks, it is desirable that the model is not rigid. However, since CoppeliaSim provides only rigid body models, in this study, we simply modeled the softness of the cushion by arranging 320 in 2×2 cm spring mass damper models on the seat surface. The spring modulus was determined by measuring the elastic modulus of the actual cushion. In addition, CoppeliaSim can output the load applied to the spring by API. Therefore, the pressure distribution applied to the cushion model can be calculated from the surface area of each mass and the force applied to the spring.

C. Control Method of Models

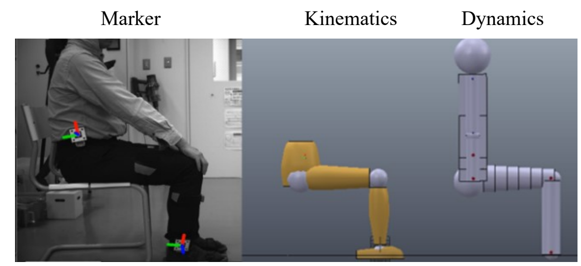
The position and posture of each part of the body are calculated based on the posture information obtained from the IMU. In this study, it is assumed that the foot is on the footrest of a wheelchair and the foot is fixed. Therefore, the mechanistic calculation is performed using the foot as the root. However, since the simulation is not stable when both feet are fixed to the environment, an open-loop system is used in which only the right ankle is fixed. By using the posture matrix obtained from the IMUs of two adjacent body segments, the change in the position of each joint can be calculated.

D. Validation Experiments for Control Method

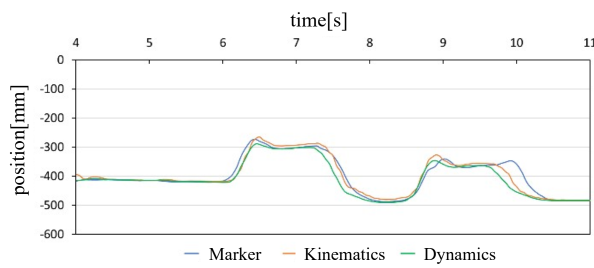
we compare the non-dynamics model behavior in the control method using the IMU described so far with the actual human behavior. We also compare the behavior of the dynamics model with that of the non-dynamics model. In addition, the pressure distribution between the seat surface by the dynamics model and the cushion model is compared with the actual measurement to verify the validity.

In this verification, the same motion is generated on CoppeliaSim using the control method described in the previous chapter, and compared with the motion of a real person. The object of comparison is a high-precision marker from the National Institute of Advanced Industrial Science and Technology [11]. These high-precision markers have higher position and orientation accuracy than conventional visual markers. These high-precision markers were attached to the ankle and waist positions, and the coordinates of the waist marker in the camera coordinate system were obtained.

The results are shown in Fig. 3 below. Since the wheelchair motion has a large movement in the sagittal plane, only the coordinates of the hips in that plane were compared, and since there was almost no difference between Non-dynamics and dynamics, it was found that there was no influence of inertia by dynamics in the motion that moves the hips back and forth. In addition, when the coordinate data of the waist by CoppeliaSim and the coordinate data of Marker are compared, the rise time of the value is almost equal, but the convergence of the value is faster in CoppeliaSim. This may be due to the fact that the dynamics model has only one degree of freedom in each joint, while the non-dynamics model has three degrees of freedom in all joints, and also due to the difference in the position of the IMU. On the other hand, when the model was not moving, there was no difference in the coordinates between Marker and CoppeliaSim. The correlation coefficients of the waveforms of Marker and non-dynamics and Marker and dynamics were 0.96 and 0.93, respectively. Therefore, although this simulation has some problems in terms of dynamics accuracy, it is effective for understanding the trend of the motion.



(a) Simulation model and markers



(b) Comparison of measurement results and estimation results

Fig. 3. Accuracy verification result of the estimation result of the joint position based on the joint angle.

E. Validation Experiments for Proposed Simulator

Experiments to verify the effect of the developed simulation was performed.

1) Experimental Conditions: The simulator was evaluated by measuring the IMU and the pressure distribution sensor at the same time. The simulator was evaluated by measuring the IMU and the pressure distribution sensor at the same time. Simultaneous measurements experiment of movements and sitting pressure during wheelchair rowing for four non-disabled adult females and one male were performed, and compared them with her simulation results. The experiment was approved by the ethics review board at National Rehabilitation Center for Persons with Disabilities.

2) Result and Discussion: The whole body movement was calculated based on the posture information obtained from the IMU, and the load on the buttocks was estimated by the simulator developed in this study. The experimental results are shown in Figs 4-6. Figure 4 shows a snapshot of a wheelchair rowing motion simulated. Figure 5 is an example of pressure distribution. Figure 6 shows the calculation results of Center of Pressure(CoP) in the x-axis and y-axis directions of the experimental collaborator A. The blue line is the measured value and the orange line is the simulation result.

As can be seen from Fig. 5, there are similarities in that the pressure around the ischium is high and the pressure on the thigh is low. On the other hand, in the simulation, the contact area is small and the pressure around the ischium

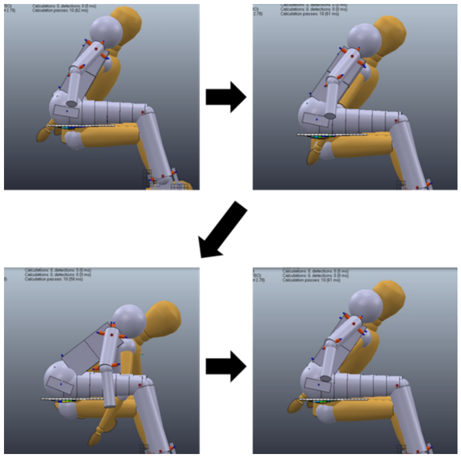


Fig. 4. A snapshot of the visualization results on a simulation of wheelchair rowing.

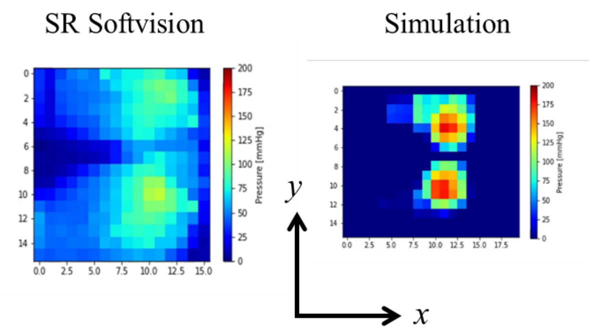


Fig. 5. Comparison of measured values of pressure distribution by SR softvision and estimation results based on simulation.

is large. It is considered that this is because the pressure on the thigh became smaller due to the influence of the taper on the thigh, and the pressure on the buttocks became relatively larger.

Comparing the CoP trajectories from Fig. 6, there is a similar tendency in the x-axis direction, but there is not much similarity in the y-axis direction. Therefore, when the correlation coefficient between the measured CoP and the simulated CoP was calculated, the x-axis was 0.612 ± 0.155 and the y-axis was 0.0904 ± 0.315. As a result, although a slightly strong correlation was found in the x-axis direction, no correlation was found in the y-axis direction. It is considered that the cause is that the pressure distribution on the left and right has changed unevenly because only the right foot is fixed to the environment.

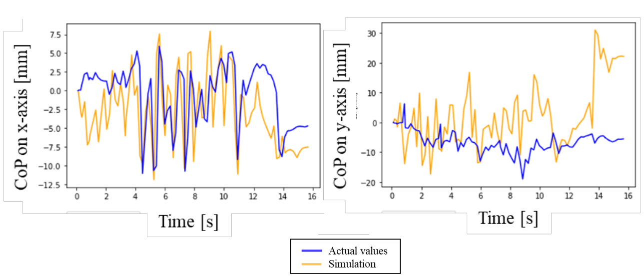


Fig. 6. CoP calculation result on the simulation.

IV. CONCLUSIONS

In this study, we proposed a simple sitting pressure simulator during wheelchair operation using a dynamics simulator. When the pressure distribution by the actual measurement and the pressure distribution by the simulator were compared, the pressure center in the wheelchair traveling direction was significantly and moderately correlated with the measured value, it was confirmed that the model can reflect the movement of the body while the wheelchair is moving.

Although this study targeted people without disabilities, the characteristics of movement differ between people without disabilities and wheelchair users. In the future, we will acquire data on actual wheelchair users. In addition, there was an error in the estimation of sitting pressure in the left-right direction. We aim to improve the simulation accuracy by examining a method for correcting the error.

ACKNOWLEDGMENT

This study was partially supported by JSPS KAKENHI Grant Number JP18H03564.

REFERENCES

[1] "National Pressure Injury Advisory Panel, NPIAP Pressure Injury Stages," https://npiap.com/page/PressureInjuryStages (accessed 2021-02-16).

[2] Yuzuru Sakuta, Makoto Takahashi, "The Interaction between Pressure and Shear Force as a Factor of Pressure Ulcers by Assessing Blood Flow Measurement", Society for Medical and Biological Engineering, volume 44(1), p101-106, 2006.

[3] Kenichi Kobara, Daisuke Fujita, Hiroshi Osaka, Tomotaka Ito, Yousuke, Yoshimura, Hiroshi Ishida and Susumu Watanabe, "Mechanism of fluctuation in shear force applied to buttocks during reclining of back support on wheelchair", Disability and Rehabilitation:Assistive Technology, 8:3, 220-224, 2013

[4] Jonathan S. Akins, Patricia E. Karg, David M. Brienza, "Interface shear and pressure characteristics of wheelchair seat cushions", Journal of Rehabilitation Research & Development (JRRD), volume 48, pages 225-234,November 3, 2011

[5] I. Hostens, G. Papaioannou, A. Spaepen , H. Ramon, "Buttock and back pressure distribution tests on seats of mobile agricultural machinery," Applied Ergonomics, Volume 32, Issue 4, p.347-355, 2001.

[6] K. Kobara, D. Fujita, H. Osaka, T. Ito, Y. Yoshimura, H. Ishida , S. Watanabe, " Mechanism of Fluctuation in Shear Force Applied to Buttocks During Reclining of Back Support on Wheelchair, " Disability and Rehabilitation:Assistive Technology, Vol. 8(3), pp. 220-224, 2013.

[7] V. Luboz, M. Petrizelli, M. Bucki, B. Diot, N. Vuillereme and Y. Payan, "Biomechanical Modeling to Prevent Ischial Pressure Ulcers," Journal of Biomechanics, Vol. 47, pp.2231-2236, 2014..

[8] "MTw Awinda - Xsens" https://www.xsens.com/products/mtw-awinda

[9] "Robot simulator CoppeliaSim: create, compose, simulate, any robot." http://www.coppeliarobotics.com

[10] Kosuke Takano, Nattawat Pinrath, Nobuto Matsuhira, Kunihiro Ogata, Tsuyoshi Nakayama, "Measurement of Daily Movements of Wheelchair Users and Elucidation of Pressure Ulcer Occurrence: Consideration of a simulation model for seating", The Society of Instrument and Control Engineers System Integration Division, 3A4-05, 2019

[11] H. Tanaka, K. Ogata, and Y. Matsumoto, "Solving Pose Ambiguity of Planar Visual Marker by Wavelike Two-tone Patterns," in Proc. 2017 IEEE Int. Conf. on Intelligent Ro-bots and Systems, 2017.