

Development of Crutch-Motion Recognition System Using RNN

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Abstract— The crutch is a temporary walking aid during treatment of injury or during rehabilitation. Patients who have to use it suddenly have few opportunities to be taught how to use them. Therefore, there are many cases where it is difficult for a patient to learn how to use a crutch. The ultimate goal of this study is to develop a system that allows patients to learn how to properly use crutches. We propose a method to recognize the crutch motion of by the RNN (Recurrent Neural Network) using data from the acceleration sensor, the gyro sensor, and the distance measuring sensor. In this paper, we report its implementation and evaluation experiment.

Index Terms— Motion recognition, RNN, Sensor

I. INTRODUCTION

Crutches are one of the walking aids temporarily used during injury treatment and during rehabilitation. However, patients who are forced to use suddenly have few opportunities to receive sufficient guidance on walking methods, so they often have difficulties acquiring how to use them. In addition, since three-point walking using a crutch is an unstable walking form, those who do not have knowledge of correct use of crutches become unbalanced usage. It can lead to further injuries. There are several studies that detect and support to recognize the states using sensors to solve this problem. This research aims to develop a system that adopts a similar approach and learn how to use crutches in real time. It is necessary to recognize the states of the crutch. In this paper, we describe the detection and estimation method using the acceleration sensor, the gyro sensor, and the ranging sensor for the motion of the crutch.

II. OUR APPROACH

A. Related studies and this study

Crutch gait has a high incidence of overuse injuries. However, crutch technology has evolved slowly compared to other assistive mobility devices. Liggins et al. [1] developed a marker-based model and protocols for crutch motion based on the kinematics of three-dimensional crutches. [2] Brooke et al. developed a single, six-axis, sensor-crutch design with an accompanying ISB-compliant, inverse dynamics model. Shahoub[3] designed a specific mat of pressure sensors to measure the hand pressure of the palm and fingers and a motion capture system to capture the movements at the shoulder and elbow. [4] Marco et al. evaluated spatiotemporal gait parameters and floor reaction force

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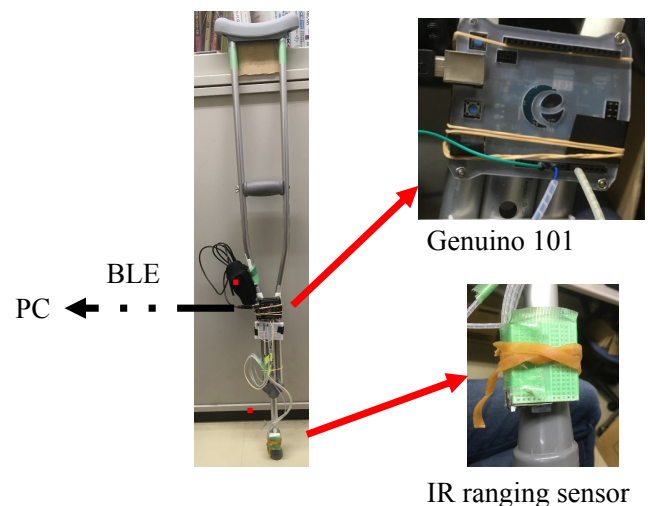


Fig.1 The setting of the Devices

(GRF) parameters of both limbs and crutch support by walking the subjects to a laboratory equipped with a motion tracking system.

In any of these researches, the approach is that human recognizes the data from sensors. The system supports human to judge the state of crutches. The purpose of this research is to recognize automatically using machine learning technology. Finally, we are planning to develop a supporting system for the usage of crutches. So, this paper describes the framework and method for crutch-motion recognition.

B. System configuration

In this research, we attach acceleration sensor, gyro sensor, and infrared distance sensor to crutches to measure the longitudinal width and lateral width angle of the crutch, the distance between the crutch and the ground. Details of the devices used below will be explained. Figure 1 shows the position of the Genuino 101 (the acceleration and gyro sensor) IR Ranging sensor which are attached to the right crutch. This system consists of Genuino 101, Infrared ranging sensor and Real-time recognition and RNN Module. implemented on Windows PC. The details are described below.

(1) Genuino 101

Genuino 101 (Arduino 101 in the United States) is a microcomputer board designed by Arduino LCC in collaboration with Intel. It is the same shape as the Arduino Uno R3, but it corresponds to BLE and has a 6 axis sensor.

(2) Infrared ranging sensor

The infrared ranging sensor converts the reflection time of distance measuring sensors. This system uses “GP2Y0E02A” as IR Ranging sensor. The position of the infrared ranging

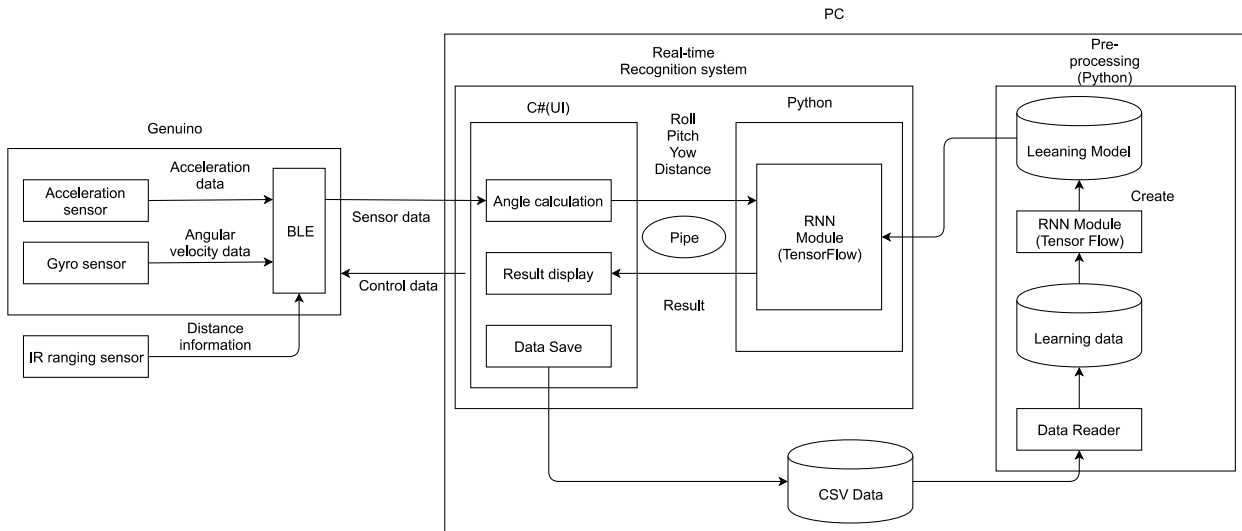


Fig. 2 System configuration

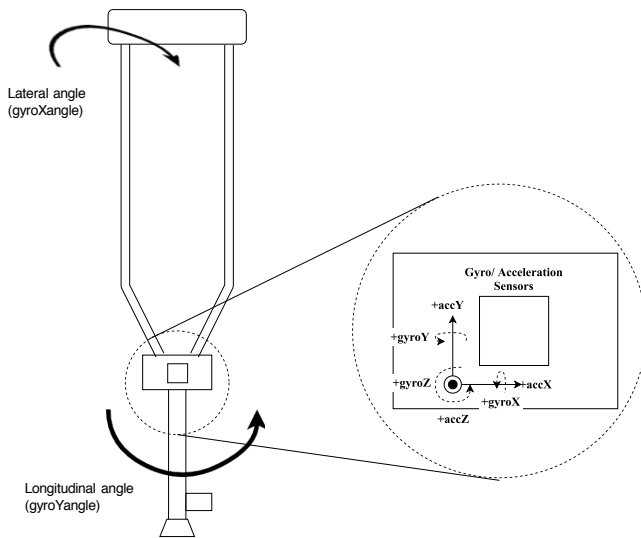


Fig. 3 The setting of devices and the axis

sensor, and the direction of the axis. Figure 2 shows the outline of system configuration. This module is connected to Genuino and sent to PC via BLE.

(3) Real-time Recognition system

This module receives sensor data from Genuino via BLE. Then, the data is passed to the RNN module to identify the motion. Reception processing via BLE is implemented by C# program including a user interface. The user confirms the received sensor data through the user interface. The RNN module uses the TensorFlow library, which is implemented by Python. Data exchange between C# program and Python program uses Pipeline processing and realizes real-time processing.

(4) Pre-processing module

This module performs pre-learning processing. The above-mentioned Real-time Recognition system has a function of saving data from sensors in CSV format. This module uses preliminary learning by using the CSV file. This module also uses the TensorFlow library and is implemented by Python.

C. Method for detecting longitudinal and lateral width angles of crutches

In this system, the acceleration sensor, the gyro sensor and the infrared distance sensor are attached to the crutches to obtain the vertical width / horizontal width angle of the crutch and the distance between the tip of the crutch and the ground as shown in Figure 2. Details of the distance measuring sensor are shown below.

In this research, accelerometers and gyro sensors were used to detect longitudinal and lateral angles of crutches. The longitudinal width angle and lateral width angle of the crutches obtained from the acceleration sensor are calculated from the equations (1) and (2). The longitudinal width angle is “accYangle”, the lateral width angle is “accXangle”, the gravitational acceleration in the X axis direction is “accX”, the gravitational acceleration in the Y axis direction is “accY”, and the gravitational acceleration in the Z axis direction is “accZ”.

$$\text{accXangle} = \tan^{-1}(\text{accZ}/\sqrt{\text{accX}^2 + \text{accY}^2}) \div \pi \times 180 \quad (1)$$

$$\text{accYangle} = \tan^{-1}(\text{accX}/\sqrt{\text{accY}^2 + \text{accZ}^2}) \div \pi \times 180 \quad (2)$$

The longitudinal width angle of the crutch is calculated from equation (3).

The lateral width angle of the crutch is calculated from the equation (4). gyroYangle is vertical angle, the horizontal angle is gyroYangle, the gravitational acceleration in the X axis direction is gyroX, the gravitational acceleration in the Y axis direction is gyroY, the gravitational acceleration in the Z axis direction is gyroZ, and the time is t.

$$\text{gyroXangle} = \int -\text{gyroX} \, dt \quad (3)$$

$$\text{gyroYangle} = \int \text{gyroZ} \, dt \quad (4)$$

Further, in the equations (3) and (4), there is a drift error due to the integration processing of the longitudinal width angle and the lateral width angle of the crutch from the gyro sensor. In the present study, these errors were reduced by using Kalman filter.

TABLE I
HYPER PARAMETER OF GRU

Parameters	Value
Input layer	8
Frame	30
Output layer	4
Hidden unit	64
Epoch	1000
Batch size	100
Learning	0.0005

TABLE II
THE RATIO OF FORWARD

	Forward	Right	Left	Stationary
A	14	0	17	69
B	48	3	5	44
C	84	10	2	3
D	90	3	0	7
E	75	2	14	9
F	85	10	2	3
Avg(std)	66(29.6)	4.7(4.3)	6.7(7.1)	22.5(27.6)

TABLE III
THE RATIO OF RIGHT-TURNING

	Forward	Right	Left	Stationary
A	2	98	0	0
B	54	42	0	4
C	17	83	0	0
D	11	85	2	3
E	57	38	0	5
F	34	60	4	1
Avg(std)	29.1(22.9)	67.7(24.7)	1.0(1.7)	2.2(2.1)

TABLE IV
THE RATIO OF LEFT-TURNING

	Forward	Right	Left	Stationary
A	0	0	100	0
B	10	0	90	0
C	41	0	59	9
D	10	0	82	18
E	6	0	76	5
F	30	0	70	0
Avg(std)	16.2(15.8)	0(0)	79.5(14.6)	5.3(7.2)

TABLE V
THE RATIO OF STATIONARY

	Forward	Right	Left	Stationary
A	7	6	4	83
B	10	10	60	20
C	8	30	3	59
D	43	6	5	46
E	13	13	5	68
F	12	1	36	51
Avg(std)	15.5(13.7)	11(10.2)	18.8(23.8)	54.5(21.4)

D. Motion Recognition Using RNN

RNN was used to recognize the states of crutch-motion. The method used in this research will be explained below. This system uses GRU as RNN model. GRU has a mechanism of choosing information called "gate" to alleviate the gradient elimination problem occurring in RNN. The input data is a total of eight types of "vertical width angle", "horizontal width angle", "rotation speed" and "distance from the infrared distance measuring sensor". The input dataset consists of 240 data (30 * 8) for 30 frames data. This model recognizes one of "forward", "left-turning", "right- turning" and "stationary" state from the input dataset.

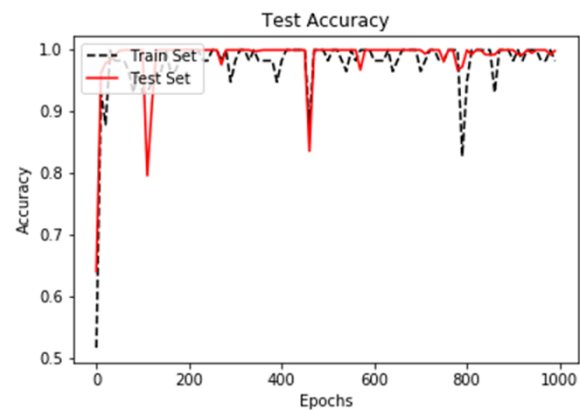


Fig. 4 Accuracy of pre-learning model

Figure 4 shows the accuracy of the pre-learning model. This model was made by 194 "forward" patterns, 220 "right-turning" patterns, 251 "left-turning" patterns and 253 "stationary" patterns. The details of the hyperparameters of the set GRU model are listed in the Table 1. RNN model was developed by TensorFlow Library.

III. EVALUATION

A. Outline

This evaluation confirms the accuracy of this system operation recognition. There are five subjects in the evaluation experiment. They used the crutches and carried out experiments in the following four procedures.

- (1) 10 times forward movement
- (2) 10 times rightward turning action
- (3) 10 times leftward turning action
- (4) 10 times Stationary states

Experimental-PC is "GS63VR 6RF Stealth Pro (Ram 8GB, GeForce GTX1060, MSI)".

B. Method

The subjects of six subjects are subjects A, B, C, D, E and F. The results of the evaluation experiments are shown in Table 2, 3, 4 and 5. Table 2 shows the ratio of the forward determination result, Table 3 shows the ratio of the right turning conversion judgment result. Table 4 shows the ratio of the left turning determination result, Table 5 shows the ratio of the stationary state determination result.

C. Result and Consideration

Tables 2 to 5 show that the standard deviation value is large. This means that the accuracy differs for each user. That is, it shows low versatility of the learned model of this experiment. Examination of the details of the experimental results showed that subjects A and B tended to take short steps in forward action. This behavior seems to have lowered the accuracy of A and B. In addition, the accuracy is not high even when the system-developer (Subject F) uses this system in this evaluation. Therefore, it is necessary to improve the learning model and increase the input data and aim for further improvement in accuracy. For the stationary state, the system tended to output the result late. This resulted in a time lag between the judgment of the subject and the recognition of the system. This may have reduced its accuracy.

IV. CONCLUSION

In this research we attempted to recognize the crutch-motions using RNN. However, it was possible to improve only the right turning and the left turning. And it was not a desirable result in terms of improving the accuracy of the crutch-motion recognition. There are some problems to be improved in the future.

The one is the problem of the improved accuracy. In this evaluation, the system used data from only one person in the pre-learning, so its model has low versatility. By using data from multiple people it is expected to improve the accuracy of the model.

Also, since there are only eight kinds of input data, it is possible to expect improvement in accuracy as well by increasing the types of data. In this research, "raw data of infrared ranging sensor" was adopted as input data as the information of grounding. However, this contains a lot of noise. Therefore, we will prepare a filter (new recognition model) of "ground judgment" that recognize whether it reaches the ground or not. Then, we will attempt to improve accuracy by using a multi-stage recognition model.

REFERENCES

- [1] A.B. Liggins, D. Coiro, G.W. Lange, T.E. Johnston, B.T. Smith and J.J. McCarthy, The Case for Using Instrumented Crutches During Gait Analysis, Proceedings of the IEEE 28th Annual Northeast Bioengineering Conference, pp.15-16, 2002
- [2] Brooke A. Slavens, Neha Bhagchandani, Mei Wang, Peter A. Smith, Gerald F. Harris, Motion Analysis of the Upper Extremities During Lofstrand Crutch-Assisted Gait in Children with Orthopaedic Disabilities, Journal of Experimental & Clinical Medicine, Volume 3, Issue 5, Pages 218-227, 2011
- [3] Shahoub Sherif, Syed Hasan, Graham Arnold, Rami Abboud, Weijie Wang, Analysis of hand pressure in different crutch lengths and upper-limb movements during crutched walking, International Journal of Industrial Ergonomics, Volume 53, Pages 59-66, 2016
- [4] Marco Freddolini, Francesco Esposito, Massimiliano Marcucci, Andrea Corvi, Palmina Braccio, Leonardo Latella, Does crutch length influence gait parameters after total hip replacement surgery?, Gait & Posture, Volume 60, February 2018, Pages 262-267