Functional Independence Measure Motor Score Estimation Method Considering Instability of Movement

Taku HIROTA*, Yuri HAMADA *, Takashi KABURAGI** and Yosuke KURIHARA *

* Aoyama Gakuin University, 5-10-1 Fuchinobe, Chuo-ku, Sagamihara, Kanagawa 2525258, Japan
** International Christian University, 3-10-2 Osawa, Mitaka-shi, Tokyo 181-8585, Japan

Abstract: In Japan, stroke is the second leading cause of long-term care. Therefore, patients with stroke need long-term rehabilitation. The Functional Independence Measure (FIM) is a measure of activities of daily living in stroke patients, which is a reliable physical therapy assessment that can be used in a multidisciplinary setting. However, the FIM scores are assessed by experienced nurses and difficult to assess accurately at home. In this study, we developed a system to estimate the FIM score easily at home using angular velocity from the target bodily movements using gyrosensors. Here, there are two types of target bodily movements: rising from a bed and sit-to-stand (STS) movement. To consider the instability of the two target bodily movements, the sum of vibrations was calculated from the acquired angular velocity time series data as features. We performed a Gaussian process regression analysis with the features as explanatory variables and the FIM motor score assessed by the nurse as an objective variable. Finally, we performed a series of experiments to evaluate the proposed method and calculated the root mean square error (RMSE) between the estimated FIM motor score and that assessed by the nurse. As a result, the RMSE with the lowest result was 10.42.

Keywords: Stroke, FIM, Rehabilitation, Gyro, Regression Analysis

1. INTRODUCTION

With the rapid aging of the population, approximately 1.17 million patients are bedridden and forced to lead a crippled life with residual symptoms such as motor paralysis and gait disorders due to cerebrovascular diseases [1]. It is the second leading cause of long-term care [2]. If our bodies remain immobile, we soon experience a decline in function, such as weakening of the muscles in our limbs, stiffening of the joints, and loss of strength. Therefore, it is important to carry out appropriate rehabilitation from an early stage. Although it is necessary to recover the decreased functions through rehabilitation, motivation may decrease during rehabilitation because the patient must continue to perform painful movements. In rehabilitation, it is important for patients to objectively confirm the process of recovery of decreased functions, which leads to increased motivation.

The Functional Independence Measure (FIM), a measure of activities of daily living (ADL), in stroke patients, is one of the most reliable physical therapy assessments that can be used in a multidisciplinary setting. The FIM instrument measures two unidimensional domains of motor function (13 items) and cognitive function (5 items), and each item is rated on a 7-point scale from 1 (total dependence) to 7 (total independence) [3]. However, calculation of the FIM score requires experienced nurses, and it is difficult to evaluate them easily and accurately. If someone can check the FIM score at home, patients with stroke can monitor the recovery status of their ADL daily, which encourages their rehabilitation.

In this study, we propose a method that uses gyrosensors to measure target bodily movements and estimate the FIM score easily at home. Here, we focus only on the FIM motor score to estimate the FIM score because the FIM cognitive score should be scored while communicating with the patient. Therefore, we developed a system to estimate the total scores for 13 FIM motor items from the target bodily movements.

2. TARGET BODILY MOVEMENT

In the rehabilitation of paralyzed patients, to prevent them from becoming bedridden, the body should be moved from the early stage of paralysis to prevent the remaining functions from deteriorating. In other words, evaluation focusing on ADL is very important. In this study, the target bodily movements are “rising from a bed” and “sit-to-stand (STS) movement,” necessary as preliminary steps for standing balance and walking. Using these two target bodily movements, we considered a method for quantitative evaluation of the ability to perform ADL. Here, to reduce the constraint on the participants and to keep the system as simple as possible, we focus on the movement of the upper body during the target bodily movement.
2.1 Rising from a bed

This movement was categorized into five phases below, and Figure 1 shows the sequence of operations from the start to end of the target bodily movement. Each of these phases is described below:

- **Phase 1**: Dorsal position
- **Phase 2**: Get up of the bust
- **Phase 3**: Rotation
- **Phase 4**: Lower at the bed
- **Phase 5**: Sitting position

We define a relative Cartesian coordinate system with the center of the human waist as the origin, y-axis in the direction of the spinal cord (frontal plane), x-axis from the right femur to the left femur (horizontal plane), and z-axis from the front to the back (sagittal plane). This coordinate system moved according to the movement of the subject. As can be seen in Figure 1, rotational movement is the main movement in this target bodily movement.

2.2 STS movement

STS movement is frequently needed to make transitions of movements in daily activities. STS failures for elderly people and people with mobility impairment result from either weakness, balance control and coordination impairment, or both, resulting in an insufficiently energetic effort [4]. A division of STS on phases has been analyzed by [5], which is as follows:

- **Phase 1**: Movement begins
- **Phase 2**: Transfer
- **Phase 3**: Extension
- **Phase 4**: Stabilization

As shown in Figure 2, we define a relative Cartesian coordinate system with the origin at the center of the human hip, y-axis in the direction of the spine, x-axis from the right femur to the left femur, and z-axis in the front. Focusing on the trunk movement, see Figure 2. In the standing up movement, the trunk is bent forward around the hip joint and then bent backward around the hip joint in a rotational motion. In general, hemiplegic patients with cerebrovascular diseases have difficulty in hip flexion in phase 2. For this reason, they try to stand up by twisting their trunk or rocking from side to side, but the forward shift of their body weight is insufficient, making it difficult for them to stand up smoothly. Contrastingly, it has been reported that normal people stand up quickly, and demonstrate a small amount of trunk lateral flexion, trunk lateral shift, and trunk rotation despite large amounts of trunk forward flexion and upward activity during STS [6]. Therefore, in evaluating STS, the forward–backward tilt (x-axis), sway (y-axis), and left–right sway of the trunk (z-axis) can be important indicators.

3. PROPOSED ARCHITECTURE OF FIM MOTOR ESTIMATION SYSTEM

3.1 Measurement system

In this study, we used a gyrosensor, which is a compact and relatively inexpensive device, to measure the angular velocity of rotation associated with rotational motion. To rise from a bed, when the rotation angles around the x-, y-, and z-axes in Figure 1 are defined as the roll, pitch, and yaw angles, respectively, their rotational angular velocities are defined as $\omega_x(t)$, $\omega_y(t)$, $\omega_z(t)$, respectively. Doing the same for STS movement, the rotational angular velocity of the roll angle, pitch angle, and yaw angle are defined as $\omega'_x(t)$, $\omega'_y(t)$, $\omega'_z(t)$.
respectively, where \( t \) is the discrete time. If the gyrosensor is used for a long time, a drift may occur. The effect of the drift can be avoided by subtracting the direct current component measured in the stationary state until the start of the target bodily movements from the data for the entire measurement period. Under the installation conditions described above, we measured the angular velocity during the target bodily movement.

### 3.2 Calculation features

The angular velocity obtained from the gyrosensor contains white noise. Thus, we use the Kalman Smoother for denoising before computing the features. Moreover, after applying a Kalman smoother, we normalize for each of the angular velocities to effectively account for oscillations in each data. We use scaling by standard deviation as normalization in this study. In brief, the features are computed after applying the Kalman smoother and normalization.

One of the causes of motor function decline due to the sequelae of cerebrovascular diseases is the loss of control of some muscles. Due to the loss of muscle control function, posture change control and posture maintenance control do not respond according to one’s volition. Thus, due to insufficient range of motion of the trunk and balance function, the target bodily movements become unstable, and the time until the desired movement is completed becomes more than that of healthy people. Therefore, to take the above two points into account, we use the following two equations.

\[
\begin{align*}
r_c & = \sum_{t=1}^{T} |\omega_c(t) - \omega_c(t-1)| \quad (c \in x, y, z) \\
s_c & = \sum_{t=1}^{T} |\omega'_c(t) - \omega'_c(t-1)| \quad (c \in x, y, z)
\end{align*}
\]

where \( T \) is the end time of the target bodily movements, which should be fixed regardless of the type of movement, patients, or normal people. In addition, the features for rising from a bed are denoted by \( r_c \), and the features for STS movement are denoted by \( s_c \). By using \( r_c \) and \( s_c \), we can account for instability in the target bodily movements. In short, the larger the value of \( r_c \) and \( s_c \), the more unstable the target bodily movement. This is because movement instability leads to the frequency of oscillation in the angular velocity time series data.

### 3.3 Method of FIM motor scores estimation

To estimate the FIM motor scores, we prepare the training phase and estimation phase. In the training phase, we built regression equations with the features \( r_c \) and \( s_c \) as explanatory variables and the FIM motor scores, \( F_{true} \), assessed by the nurse as an objective variable. Meanwhile, the Gaussian process regression was used for training. In the estimation phase, first, the angular velocity \( \omega_c(t) \) \( \omega'_c(t) \) is obtained from a patient with unknown FIM scores, and the features \( r_c \) and \( s_c \) are calculated. Subsequently, the estimated scores of the FIM motor scores, \( \hat{F} \), can be obtained by inputting it into the regression equations built in the training phase.

### 4. CLINICAL EXPERIMENTS

In this study, we perform the above process for the number of features six times to compare the validity of each feature. As a method for assessing the validity, we calculated the root mean square error (RMSE) between the estimated FIM motor score and that assessed by the nurse.

#### 4.1 Experimental methods and participants

We used the 3D gyrosensors, which are the basic elements of the measurement method, and the coordinate system for measuring the angular rate at each gyrosensor. The gyrosensor used was a Murata ENC-03J, which is small and light, measuring 15.5 mm × 8 mm × 4.3 mm and weighing 2.7 g. The 3 gyrosensors were arranged orthogonally and placed in a 50 mm × 30 mm × 20 mm case. The output of the gyroscopes should be positive when rotating in the direction of the arrow in Figure 1 and Figure 2. During measurement, the 3D gyroscope is fixed on the participant’s sternum using a sports belt, which allows easy installation and adjustment for each participant.

We conducted a clinical experiment using the system described above with the cooperation of patients who have paralysis as the sequelae of cerebrovascular diseases, after obtaining their informed consent. The participants were 20 patients (62.7±9 years old) undergoing rehabilitation. The gyrosensor was attached, and the participant was asked to perform the target bodily movement. In this experiment, the participant performed the target bodily movement by himself without any support from a caregiver. The angular velocities measured by the gyrosensor are A/D-converted at a sampling interval of 0.05 s, and the parameters for evaluation were calculated on a personal computer. The FIM scores were evaluated by a different nurse for each patient (average working years: 10.2 ± 2.3 years). The same participant was measured multiple times with an interval of approximately one month, for a total of 44 measurements.
4.2 Evaluation method

In this experiment, we used 43 of the 44 datasets to build the regression equations; that is, leave-one-dataset-out cross-validation was performed. The remaining datasets were used to estimate the FIM motor score $\hat{F}$. We calculated the $RMSE$ by using the FIM motor scores, $F_{\text{true}}$, assessed by the nurse and the estimated FIM motor score, $\hat{F}$. In this study, by using $RMSE$ and correlation coefficients between the estimated FIM motor score, $\hat{F}$, and that, $F_{\text{true}}$, assessed by the nurse, we compared the validity of six features $r_c, s_c$.

$$RMSE = \sqrt{\frac{1}{44} \sum_{n=1}^{44} (\hat{F}_n - F_{\text{true}})_n^2}$$

(3)

4.3 Results and discussion

Table 1 summarizes the correlation coefficients between the estimated FIM motor scores $\hat{F}$ and the features $r_c, s_c$, in addition to $RMSE$. As shown in Table 1, the most optimal feature to estimate the FIM motor scores was $r_y$ — the lowest $RMSE$. However, the best result for the correlation coefficient was found for $s_y$, which showed the lowest $RMSE$ among STS movements. In addition, comparing the results of rising from a bed and that of STS movement, we can see that on average, that of rising from a bed is better. In addition, for rising from a bed, the y-axis was valid, and for STS movement, the z-axis was valid.

| Correlation coefficient | $r_x$ | $r_y$ | $r_z$ | $s_x$ | $s_y$ | $s_z$ |
|-------------------------|-------|-------|-------|-------|-------|-------|
| $RMSE$                  | 11.05 | 10.42 | 12.39 | 13.48 | 14.45 | 11.14 |

5. CONCLUSION

In this study, we propose a system to measure “rising from a bed” and “STS movement” using a three-dimensional gyrosensor. With this system, we were able to obtain the angular velocity around the x-, y-, and z-axes in a three-dimensional relative coordinate system. To consider the instability of the target bodily movements, the sum of the vibrations was calculated from the acquired angular velocity as features. The efficacy of these features was examined and compared in clinical experiments. The result with the lowest $RMSE$ was 10.42, and the best correlation coefficient showed a high correlation (-0.74).

In conclusion, it is easy to estimate the FIM motor score with relatively high accuracy using gyrosensors. This increases the motivation for rehabilitation and leads to improvement in ADL. In the future, to improve the accuracy of the estimation, we want to re-examine features and consider combinations of multiple actions.

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