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DEVELOPMENT OF TRIPPING RISK EVALUATION SYSTEM INTERMS OF MINIMUM TOE CLEARANCE USING GROUND REACTION FORCE

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SUMMARY

We propose a method that can estimate the risk of tripping in terms of minimum toe clearance (MTC) while walking without require the users to measure his/her own gait prior to the services and to wear some sensors. Our methods estimate the MTC from a model that made from gait data of third persons, and the ground reaction forces (GRF) during walking. First, we measured the GRF and the MTC of one gait cycle from 26 health young and 6 healthy elderly participants. Second, we build total 10 models to estimate the MTC from the GRF, from randomly chosen 20 of 26 young participants' data (Group A_1 to Group A_{10}). Stepwise multiple regression analysis has used to build the models. The robustness of the proposed method has evaluated with the contribution ratio and independent variables between the models. Moreover, the accuracy of the proposed method has evaluated with the root mean squared error (RMSE) and coefficient of correlation between the estimated MTC and the actual MTC that derived from the remaining data of 6 young (Group B_1 to Group B_{10}) and 6 elderly participants (Group C_1 to Group C_{10}). As a result, the contribution-ratio of the models was 0.67±0.03 and 5 independent variables were commonly used to build the models. Moreover, RMSE between the estimated MTC and the actual MTC were 4.6±0.7mm for group Bs and 6.4±0.5mm for group Cs. Further, the coefficient of correlation between the estimated MTC and the actual MTC were significant for both group Bs and group Cs. From these results, we concluded that proposed method can build robust model regardless of the data groups, and may use for initial screening of the tripping risk. Further, we installed the proposed method that modified for the treadmill system in a custom made treadmill system with force sensors so that we can use it for the initial screening of the risk of tripping in various fields.

INTRODUCTION

Tripping while walking is known as the leading cause of the falling. It has been reported that there are significant differences in the variability of minimum toe clearance (MTC) while walking between people with high risk of tripping and people with low risk of tripping. Thus, several researchers proposed a method to estimate the MTC by using the model made from the data of the users, and acceleration that derived from accelerometers attached to the foot or shank of the users [1,2]. However, such systems require the users to measure his/her own gait prior to start the services and to wear some kind of sensors to estimate the MTC.

In this study, we proposed a method that can estimate the MTC from the model that made from the data of third persons, and ground reaction force (GRF). This way, users do not have to measure his/her own gait prior to start the services, and to wear any sensors. We test the robustness and accuracy of the method, and installed the method to the custom build system using a treadmill and force sensors.

METHODS

Participants were 26 healthy young and 6 healthy elderly adults. Motion and GRF were measured by using motion capture system and force plates while participants were asked to walk straight at their preferred speed and bare foot as they traversed the travel path from beginning to end. The starting position was adjusted for each participant to ensure the following 3 conditions: 1) the measurement of one gait cycle on the force plates; 2) the measurement of independent forces from each limb; and 3) a minimum of five steps before step in to and after step out from the force plates. Data of 196 trials were recorded (6 walking trials (3 right and 3 left) for 32 participant).

Raw data were digitally filtered by using a 4th order Butterworth filter with 0 lag and cut-off frequencies of 10 Hz for kinematic data and 56 Hz for force data. From each trial, one MTC was derived from the limb that stepped in to the force plates first. In present study, MTC was defined based on previous studies, such as the lowest point of the trajectory of a marker placed on the lateral aspect of the first metatarsal head during mid-swing phase. MTC were normalized with the participant's height. Right and left GRF were divided into x (medio/lateral), y (anterior/posterior), and z components. Each component was normalized by the % of gait cycle (0% to 100%) and the participant's weight.

The model to estimate the MTC from the GRF has built from 20 of 26 young participants' data (Group A) by using stepwise multiple regression analysis. Remaining data of 6 young participants (Group B) and 6 elderly participants (Group C) were used for the cross-validation. In order to confirm the robustness of the proposed method, we made 10 different group As (Group A_1 to A_{10}), and build 10 different models from each group. (Thus, we also had 10 different group B (Group B_1 to B_{10}) and group C (Group C_1 to C_{10})).

606 time-and-weight-normalized GRF data (0% to 100% data respectively from each right and left, and x, y, and z time-and-weight-normalized GRF components) were used as independent variables and height-normalized MTC were used as dependent variable. Since so many data were used as the independent variables, a problem of multicollinearity among the data may be suggested. However, the purpose of this model is only to predict the height-normalized MTC from a set of time-and-weight-normalized GRF, and not to analyze how each data affect the height-normalized MTC. Thus, we believe multicollinearity is not a problem in this model. After the estimation of the height-normalized MTC, the units were returned to millimeters (mm) by multiplying by the participant's height.

The robustness of the proposed method has evaluated with the contribution ratios and independent variables that derived from the data of the group A_1 to A_{10}. The accuracy of the proposed method has evaluated with the root mean squared error (RMSE) and coefficient of correlation between the estimated MTC and the actual MTC that derived from the data of the group B_1 to B_{10} and the group C_1 to C_{10}.

RESULTS AND DISCUSSION

The contribution-ratios of 10 models (Average ± S.D.) were 0.67±0.03. Moreover, 5 variables were commonly selected among the models. These results indicate that proposed method can build robust model regardless of the data groups. RMSEs between the estimated MTC and the actual MTC were 4.6±0.7mm for group Bs and 6.4±0.5mm for group Cs (figure 1). The coefficient of correlation between the estimated MTC and the actual MTC were significant for both group Bs (0.62±0.15, $p<.01$) and group Cs (0.46±0.10, $p<.01$).

Proposed method is less accurate than ordinary motion capture system (less than 1mm), or the system that using accelerometers and the model that made from user's own gait data (less than 4mm). However, we believe that our system has an advantage on its simpleness of the measurement procedure. Our system does not require the users to wear any sensors or to measure their gait prior to the services.

Further, we made a custom-build force treadmill system and installed the proposed method that modified for the treadmill system, so that we can use it for the initial screening of personal tripping risk in various fields (figure 2). So far, we measured more than 200 people's MTC with this system in many events as demonstration, and obtained various comments for future improvement of the system.

CONCLUSIONS

In this study, we proposed a method to estimate the MTC from the GRF and the model that made from gait data of third persons. With the assessment of the robustness and the accuracy of the proposed method, we found the accuracy of the MTC estimation was somewhat less than ordinary motion capture system or similar method using the accelerometers and the model that made from user's own gait data. However, since our system has an advantage on its simple measurement procedure, we believe that our method can be used for the initial screening of the personal tripping risks in various fields.

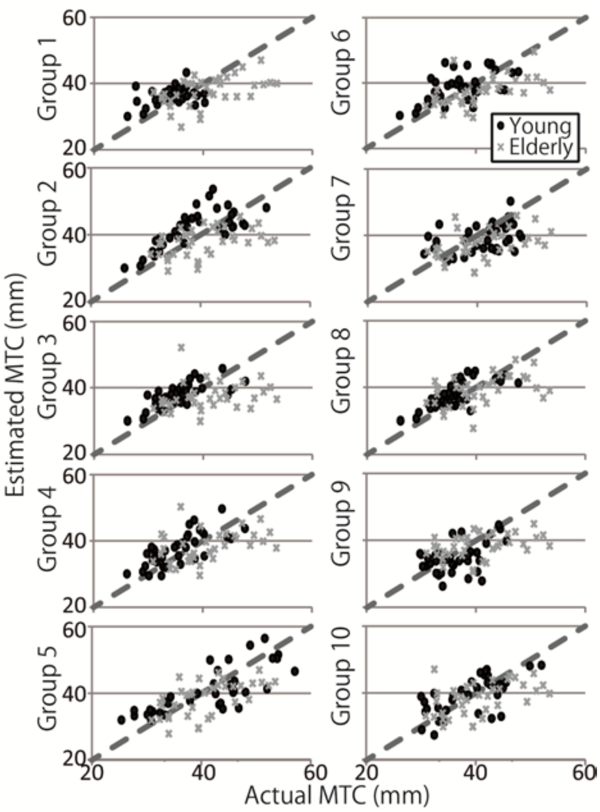

Figure 1. RMSE between the estimated MTC (vertical axis) and the actual MTC (horizontal axis) of 10 models. Blue dots indicate the result of young participants (Group B), and red dots indicate the result of elderly participants (Group C). Each dot indicates the results of each trial; thus, each figure has 72 dots (6 trials x 6 participants x 2 groups).

Figure 2. Custom-build force treadmill system that installed proposed method that modified for the treadmill system. We are now demonstrating the system in various places, and collecting many comments to improve the system.

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