Real-Time Lower-Limb Activity Recognition with Instantaneous Characteristic Features

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I. INTRODUCTION

Current activity recognition classifiers can achieve high accuracy using a high-dimensional space of features, e.g., combinations of EMG and mechanical signals. The associated classification rules are therefore complex and difficult for the human user to understand. This work presents an activity recognition system using signals from a thigh-mounted IMU and foot contact to classify transitions between sit (S), walk (W), stair ascent (SA), and stair descent (SD) using intuitive biomechanical features, named Instantaneous Characteristic Features (ICFs). These features include thigh angle (θ_{th}) and sign of thigh angular velocity ($\dot{\theta}_{\text{th}}$) at specific moments during task transitions, which are easy for the user to understand and control. This approach is inspired by thigh-based phase variable controllers for powered prosthetic legs, where the user's hip motion directly controls the progression of prosthetic joint patterns. Similarly, the user can learn simple hip-based classification rules to control task transitions with high accuracy. We trained our classifier offline using an existing dataset and assessed online performance with 10 able-bodied subjects wearing a real-time system on the thigh.

II. METHOD

We derived the thigh-based ICFs to detect transitions between distinct activities by analyzing our able-bodied human dataset [1]. Offline analysis of thigh kinematics during task transitions indicated distinct differences in thigh kinematics at specific moments in gait, namely, Maximum Hip Flexion (MHF) and Heel Strike (HS). We found that θ_{th} at MHF for SA (ICF-1) and the difference in θ_{th} between MHF and HS for SD (ICF-2) are much higher than the other activities. We only allow the transition to sit when the foot is on the ground and $\theta_{\text{th}} = 10°$ with a negative $\dot{\theta}_{\text{th}}$ (ICF-3). Based on the three ICFs, we designed a finite state machine (FSM) to break the classification into three transition detection problems (Fig. 1) with a self-contained system logic. We trained and validated each classifier using the biomechanics dataset [1] offline. Finally, we evaluated the real-time performance of the classification system in an outdoor experiment with ten able-bodied subjects. Each subject performed a total of 10 trials (5 trials before and 5 trials after a 10-minute training session on the classification rules). Each trial contained three transitions between W-S, W-SA, and W-SD.

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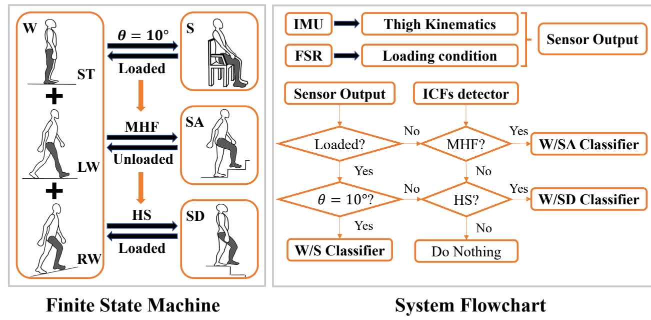

Fig. 1. Logic diagram for the activity recognition system. In the FSM, level walking (LW), stand (ST), and ramp walking (RW) are combined into the same state which can be handled by a single phase-variable controller [2]. No direct transitions are allowed between sit (S), stair ascent (SA), and stair descent (SD). In the flowchart, the ICFs detector will search for specific moments (i.e., MHF, HS) that contain different ICFs from IMU to predict the next state. Based on foot contact (FSR) and the ICF detection, different classifiers run in sequential order. Once a transition is detected, the algorithm updates the current state and breaks out of the loop.

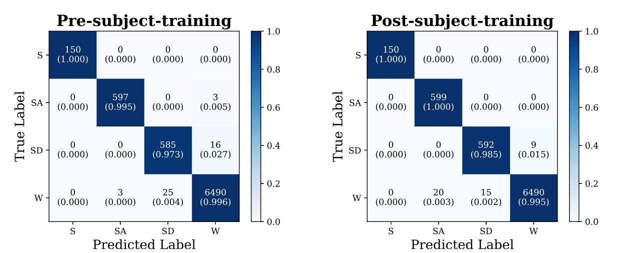

Fig. 2. Confusion Matrices for the real-time experiment before and after subject training on classification features. The y-axis represents the class from the manually labeled truth-table, while the x-axis represents the predicted class. The walking class includes ramps and turns.

III. RESULTS & DISCUSSION

The overall classification accuracy before and after subject training was 99.41% and 99.44%, respectively. According to the confusion matrix (Fig. 2), subject training lowers the false positive rate of SA and SD classification.

IV. CONCLUSIONS

Our study shows the ICF-based activity recognition system classifies transitions in real-time with an overall accuracy of 99.43%. It also demonstrates that machines and humans can mutually improve classification accuracy. Future work will implement this approach on a powered knee-ankle prosthesis.

REFERENCES

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