Real-Time Estimation of Intended Lower-Limb Motion for Assist Robots

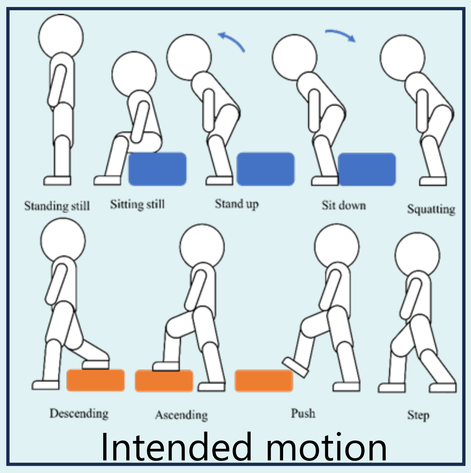
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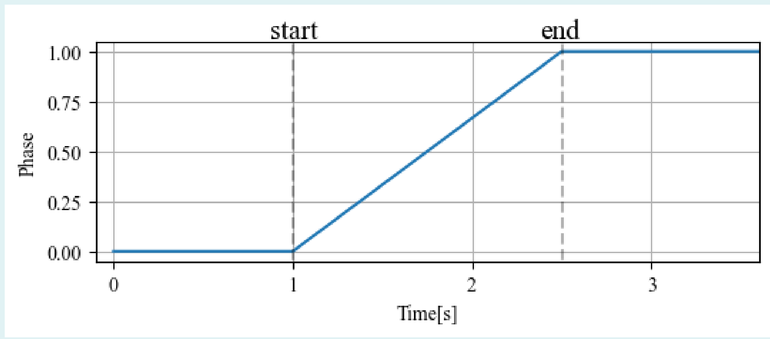
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Ⅰ. Introduction

- Human assist robots require accurate real-time estimation of user's **motion intention** and **motion phase**
- **Artificial Neural Networks (ANNs)** with **damping neurons** are applied for their accurate estimation
- The effectiveness of the proposed estimation method was evaluated with young and pseudo-elderly subjects



Intended motion



Motion phase

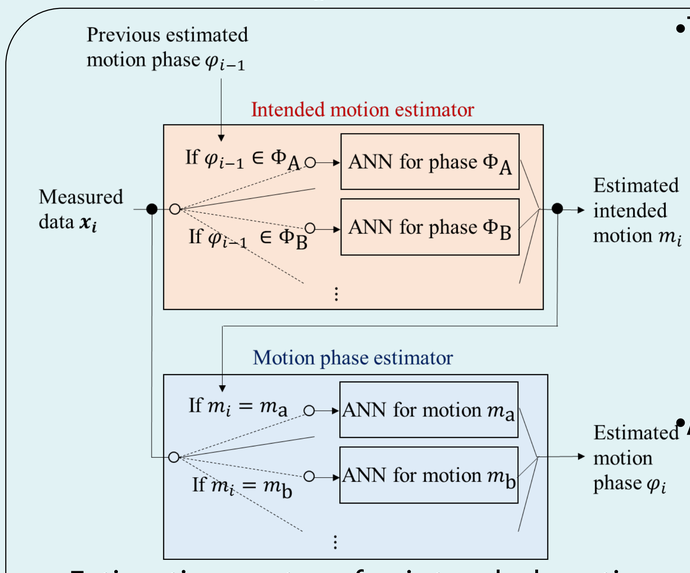
➡ This study proposes an ANN-based method for real-time estimation of intended motion and motion phase, evaluated on nine lower-limb movements, including cases of mid-movement abandonment

Ⅱ. Method

Input Information

•**Kinematic data**: 2D position, velocity, and acceleration of knee, ankle, heel, toe, and shoulders, lower limb joint angles, Zero Moment Point (ZMP), and swing leg toe-obstacle distance.
•**sEMG signals** : 8 sEMG signals (rectus femoris, biceps femoris, gastrocnemius, tibialis anterior of both legs)

Estimation System

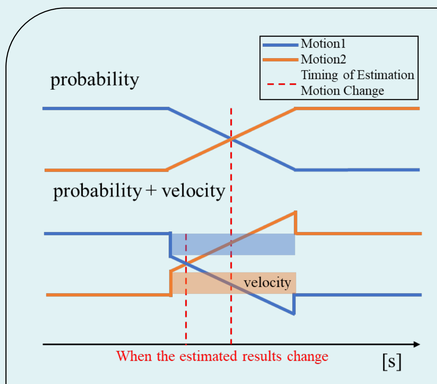


Estimation system for intended motion estimation and phase estimation

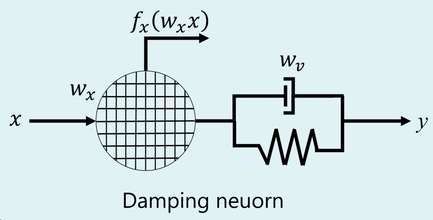
•Two **estimators**:
- **Intended Motion Estimator**: Predicts one of **nine lower-limb activities** (stand up, sit down, squatting, descending, ascending, push, step, standing still, and sitting still)
- **Motion Phase Estimator**: Outputs a value **from 0 to 1**, indicating movement progression

•**ANN switching mechanism**:
- **Motion intention estimator** switches the ANN based on phase estimation results
- **Phase estimator** switches the ANN based on motion estimation results

Intended Motion Estimation



Timing of intended motion estimation considering change of output



Damping neuorn

•**Proposed ANN**:
- The proposed ANN predicts intended motion **at an early stage** by considering ANN output changes

•**Challenge**: Early-phase motion resembles previous motion → risk of misclassification
•**Solution**: Time variation of ANN output is introduced:

$$z = y + c_v \dot{y}$$

where y is ANN output, $\dot{y}$ is time variation, and c_v is a constant
•**Damping neurons in the output layer**:

$$y = f_x(w_x x) + w_v f_v(\dot{f}_x(w_x x))$$

→ Enables better learning of dynamic features in **sEMG and motion data**

Motion Phase Estimation

•**Phase representation**: Motion phase progression (0 to 1)
•**Phase estimator adaptation**:
- Separate ANN models for each motion
- Uses **motion estimator results** to select the appropriate phase model

•**Damping neurons in hidden and output layers**: Improve dynamic learning

Ⅲ. Results

Accuracy rate of each motion with the proposed Estimation system

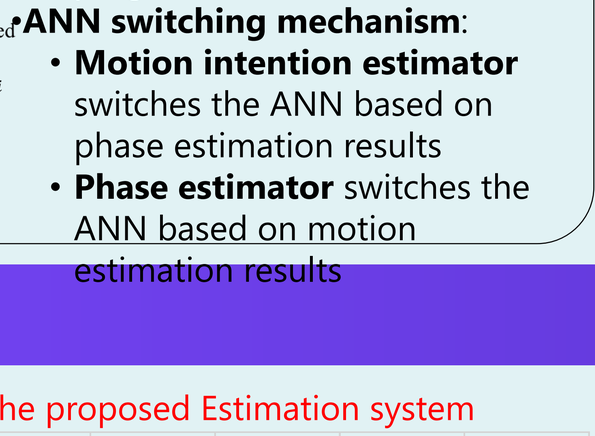
	Stand up	Sit down	Squatting	Descending	Ascending	Push	Step	Standing still	Sitting stil
0-10%	0.9680	0.9726	0.9492	0.9703	0.8737	0.9135	0.9212		
10-20%	0.9775	0.9823	0.9649	0.9717	0.9290	0.9720	0.9306		
20-30%	0.9831	0.9911	0.9679	0.9622	0.9413	0.9836	0.9300		
30-40%	0.9861	0.9968	0.9896	0.9511	0.9605	0.9793	0.9471		
40-50%	0.9881	0.9908	0.9934	0.9801	0.9815	0.9714	0.9706		
50-60%	0.9889	0.9919	0.9913	0.9759	0.9848	0.9665	0.9781	0.8963	0.9033
60-70%	0.9839	0.9939	0.9937	0.9794	0.9802	0.9820	0.9813		
70-80%	0.9759	0.9867	0.9917	0.9708	0.9659	0.9811	0.9789		
80-90%	0.9526	0.9715	0.9913	0.9087	0.8954	0.9860	0.9491		
90-100%	0.5824	0.7115	0.9910	0.7121	0.6539	0.6994	0.7843		
0-100%	0.9371	0.9584	0.9824	0.9368	0.9147	0.9429	0.9362		

Average of Accuracy rate of each motion

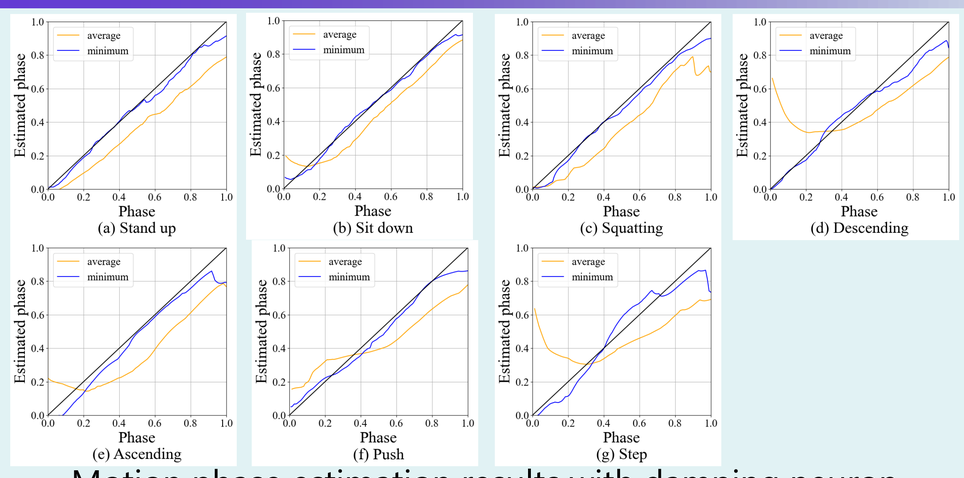
phase	standard ANN	early estimation ANN	Estimation system
0-10%	0.9136		0.9383
10-20%	0.9567	0.9633	0.9611
20-30%	0.9622	0.9640	0.9656
30-40%	0.9668	0.9679	0.9729
40-50%	0.9770	0.9740	0.9823
50-60%	0.9804	0.9754	0.9825
60-70%	0.9795	0.9769	0.9849
70-80%	0.9730	0.9687	0.9787
80-90%	0.9394	0.9247	0.9507
90-100%	0.7416	0.6678	0.7335
0-100%	0.9381	0.9318	0.9441
Standing still	0.9204	0.9105	0.8963
Sitting stil	0.9144	0.9032	0.9033

2.5% higher

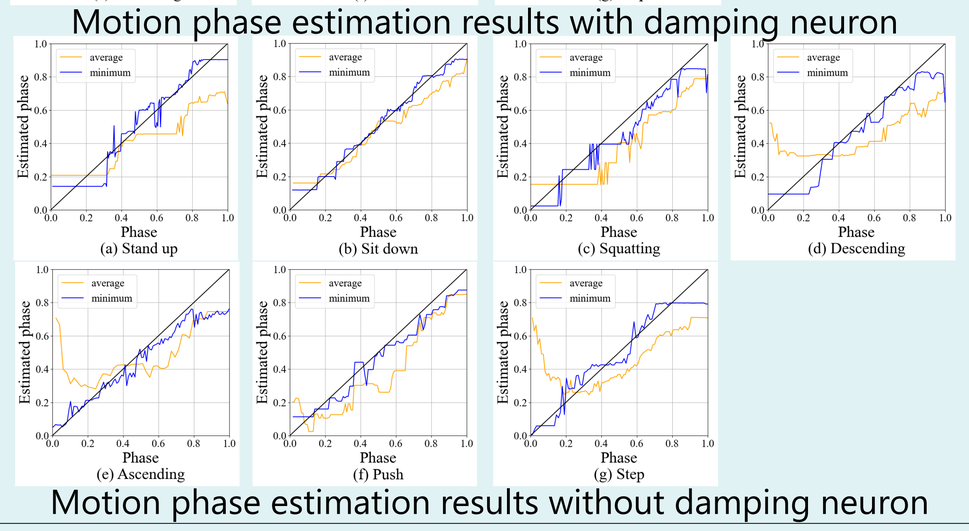
6.6% higher



Estimation results of motion intention and motion phase when the intended motion is changed



Motion phase estimation results with damping neuron



Motion phase estimation results without damping neuron

Push, squat, sit down, stand up: Estimated phase is **accurately tracked**

Ⅳ. Conclusion

- **Real-time estimation method for human motion intention and motion phase were proposed**
- **Accuracy of early estimation in initial phases was improved**
- **Phase estimation stability has been enhanced with damping neurons**
- **The user's motion intention has been effectively estimated even if the motion intention is changed during a motion**