Effect of Sensory Augmentation via Skin Stretch Feedback on Quiet Standing Balance

MECHANICAL ENGINEERING
TEXAS A&M UNIVERSITY

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INTRODUCTION

- Dysfunctional sensory systems such as vision, vestibular, and somatosensory impairments cause postural sway and increase the risk of falling.
- Studies have shown that light touch of fingers on fixed surfaces can reduce postural sway during quiet standing and walking for people with or without dysfunction of sensory systems [1].
- With the help of additional sensory information from skin stretch feedback, individuals with neurological impairments may improve their balance in activities of daily life.

Objectives

- To develop a portable sensory augmentation system that can induce skin stretch feedback.
- To examine the effect of augmented sensation at the fingertip due to the developed device on quiet standing balance of healthy young for various sensory modalities.

Hypothesis

- Augmented sensation due to skin stretch feedback enhances quiet standing balance more effectively when more sensory modalities are removed.

DEVICE DESIGN AND CONTROL

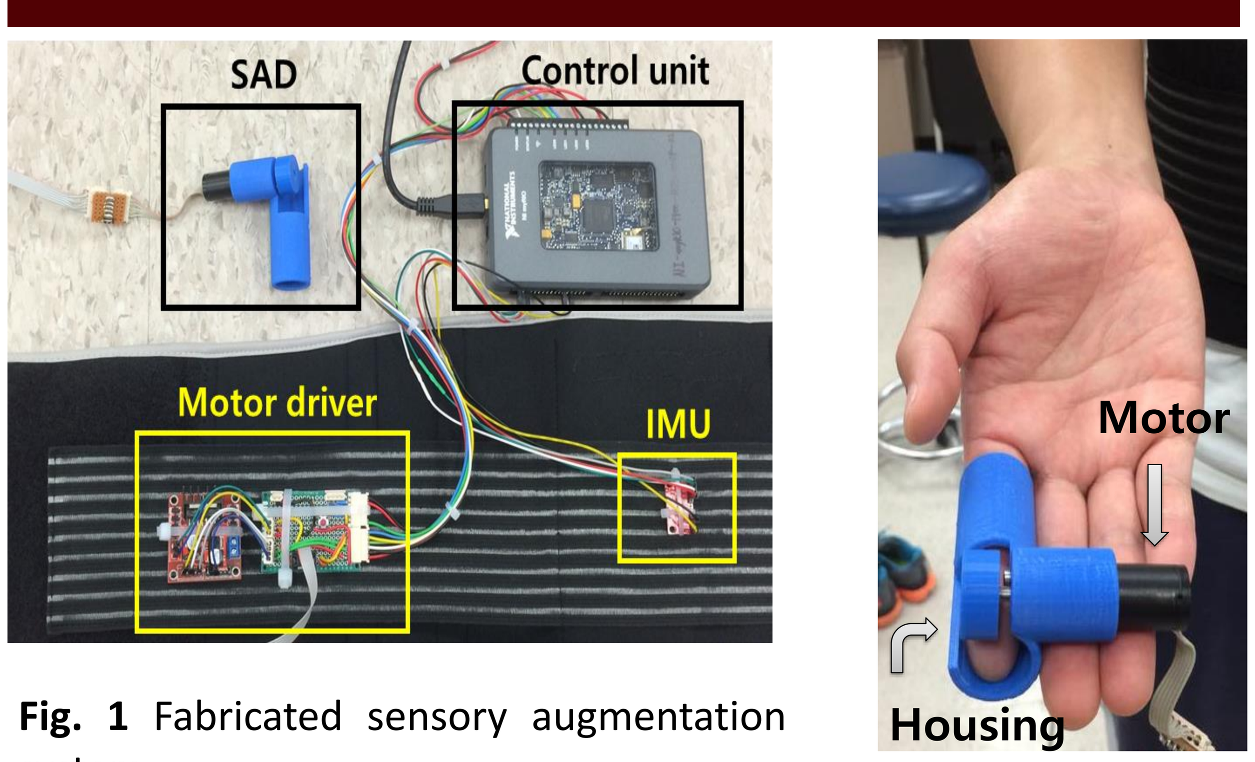

Fig. 1 Fabricated sensory augmentation system

This portable sensory augmentation system (Fig. 1) consists of

- Sensory augmentation device (SAD), which induces the skin stretch at the index fingertip pad. The DC motor is mounted at the housing of SAD where subject's index finger is inserted.
- Embedded control unit (myRIO, National Instruments).
- Motor driver.
- Inertia measurement unit (IMU).

The IMU, embedded control unit, and a motor driver are enclosed in a waist belt so that subjects can easily wear the system.

Control Strategy

- Fig. 2 shows a schematic diagram of our sensory augmentation system. The pitch angle in subject's anterior-posterior direction is calculated from the data of IMU which is attached at the waist of a subject.
- A position-based controller used data from IMU and calculated the desired angular velocity of contactor of SAD so that each subject was provided augmented sensory feedback of his/her postural sway.

EXPERIMENT PROTOCOL

To validate the efficacy of our developed SAD, quiet standing balance tests were conducted. More details are illustrated below.

Subjects

- 15 healthy young adults (4 females and 11 males) with neither neurological nor musculoskeletal impairments.

Sensory modality condition

i) Eyes-Open (EO),
ii) Eyes-Closed (EC), and
iii) Tilting Head Backwards with Eyes-Closed (HBEC).

Sensory augmentation condition

i) With SAD,
ii) No SAD.

Procedures

- Subjects were instructed to stand quietly on a force plate under three conditions of availability of sensation (EO, EC, and HBEC). In the practice session, subject's reference angle was computed to calibrate IMU.
- In the main session, 30s quiet-standing with 10 repetitions for each sensory modality condition (EO, EC, HBEC) and SAD condition (on vs. off) were performed in a completely random order. Subjects were unaware of the function of SAD.

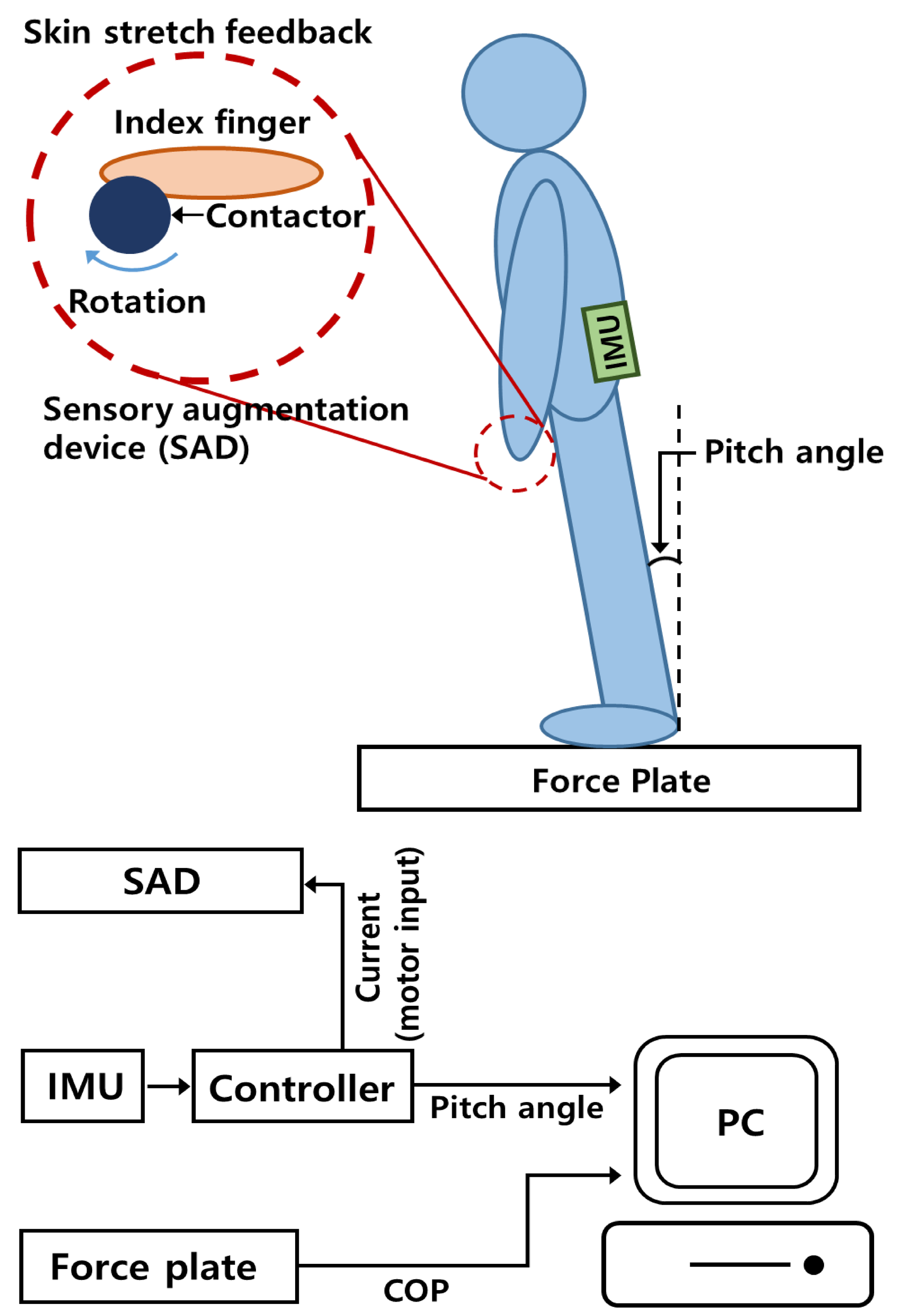

Fig. 2 Schematic diagram of sensory augmentation system.

Data Collection

- Pitch angles were measured by IMU.
- Center of Pressure (COP) data were collected from force plate.

Postural Sway Data Analysis

- Several traditional parameters such as maximum distance (*MaxDist*), range (*Range*), and mean frequency (*MeanFreq*) in anterior-posterior (AP), medial-lateral (ML) directions were computed and investigated [2].

RESULTS

- Postural sway was the smallest when all sensory information was available (EO), followed by when vision was lacking (EC), and followed by when both vision and vestibular information was deprived (HBEC) in both AP and ML direction.
- Sensory augmentation due to SAD significantly affected balance. *MeanFreqAP* and *MeanFreqML* significantly decreased when sensory augmentation was provided (Table 1). This result suggests that sensory augmentation from SAD can reduce effective postural way that cannot be captured by the mean values of postural sway.
- *MaxDistAP* and *RangeAP* had significant interaction effects between sensory availability and SAD. This interaction came from the fact that for EO/EC condition, SAD increased postural sway (*MaxDistAP* and *RangeAP*) whereas for HBEC condition, SAD decreased postural sway (Table 1). The results supported our hypothesis that the SAD improved quiet standing balance via an augmented sensory input when more sensory modalities were removed.

CONCLUSIONS

- A sensory augmentation system for postural control rehabilitation was developed using skin stretch feedback.
- The efficacy of the developed sensory augmentation system via skin stretch feedback is evaluated.
- The presence of additional sensory input helped maintaining balance when both visual and vestibular inputs were removed, substantiating our hypothesis.

References

[1] Jeka, John J. et al., *Physical Therapy* 77, no. 5 (1997): 476-487.
[2] Prieto TE et al., *IEEE Trans Biomed Eng* 43 (1996).
[3] Nashner et al., *J Neuroscience* 2, no. 5 (1982): 536-544.

Parameters	Available Sensory Modality			Sensory Augmentation		Interaction p-value
	EO (A)	EC (B)	HBEC (C)	With SAD (D)	No SAD (E)	
MaxDistAP (m)	.012 (.001)^{BC}	.014 (.001)^{AC}	.017 (.001)^{AB}	.015 (.001)	.014 (.001)	.013
MaxDistML (m)	.006 (.0005)^{C}	.006 (.001)	.007 (.001)^{A}	.007 (.001)	.006 (.001)	.184
RangeAP (m)	.021 (.001)^{BC}	.024 (.001)^{AC}	.029 (.002)^{AB}	.026 (.002)	.024 (.001)	.019
RangeML (m)	.010 (.001)^{C}	.011 (.001)	.012 (.001)^{A}	.011 (.001)	.011 (.001)	.181
MeanFreqAP (Hz)	.360 (.024)^{B}	.395 (.022)^{A}	.391 (.024)	.370 (.025)^{E}	.395 (.021)^{D}	.421
MeanFreqML (Hz)	.461 (.027)	.441 (.028)	.430 (.028)	.421 (.029)^{E}	.466 (.025)^{D}	.029

Table 1: Measures of postural sway. Value represents mean (standard deviation). Superscript denotes significant differences from indicated main effect condition ($p < .05$).