Research in Developmental Disabilities 35 (2014) 2026–2034

Contents lists available at ScienceDirect

Research in Developmental Disabilities

Navigation within buildings: Novel movement detection algorithms supporting people with visual impairments☆

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ARTICLE INFO

Article history:
Received 4 December 2013
Received in revised form 30 April 2014
Accepted 30 April 2014
Available online

Keywords:
Visual impairment
Accelerometer
Navigation
Movement detection

ABSTRACT

This study aimed at finding simple algorithms to identify three different movements registered by accelerometer and to detect differences in the acceleration signals of people with and without visual impairments.

The *Tactile Acoustical Navigation and Information Assistant* (TANIA) is construed to provide persons suffering from visual impairments support for an independent navigation indoors and outdoors. Attaining this goal, TANIA uses vertical acceleration signal extrema to assess its user's walking distance. This study investigated first the sit-to-stand movement, stumbling and walking up- and down stairs of 25 subjects with visual impairments using TANIA sensor system. The objective was to improve the user's movement detection using sensors to get valid and reliable data. In a second step of the study it was investigated if there is a difference between the above-mentioned movements in people with or without visual impairments ($n = 10$). The acceleration signals of the subjects were compared.

Three simple algorithms were found, which are able to separate the movement signals based on accelerometers of the respective daily movements. The second step analysis revealed a detectable difference in the second phase of stumbling ($p = .034$), where the subjects had to get back into walking forward. No differences in the other acceleration signals were found.

☆ The manuscript has not been previously published and has not been submitted elsewhere.

Abbreviations: a, acceleration; COM, center of motion; C5, fifth cervical vertebra; df, degrees of freedom; FTSST, five-times-sit-to-stand-test; IS, initiation step; *M*, mean; P, single Point of the acceleration graph; *p*, p-value; RFID, radio frequency identification; SC, stair ascending; SD, standard deviation; SDes, stair descending; SiSt, sit to stand; StSi, stand to sit; STu, stumble; SW, straight walking; TANIA, tactile acoustical navigation and information assistant.

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http://dx.doi.org/10.1016/j.ridd.2014.04.032
0891-4222/

1. Introduction

People navigate indoors and outdoors using their senses of balance and gravitation in combination with visual and acoustical information from the environment. They are able to navigate even if they don't know the exact way to reach their destinations. Instead, less or no vision often causes a lack of orientation (Brambring, 2008). People with visual impairments especially have to deal with wanting to manage their life and take part in social life (Hub, Diepstraten, & Ertl, 2005).

White canes and guide dogs are still the most successful "systems" concerning navigation support and obstacle avoidance to support visually impaired people to live independently. During the last decade the development of navigation systems for visually impaired individuals has greatly progressed. There are now adjuncts or even alternatives: the Sonic Pathfinder, Mowat-Sensor and the Guide-Cane, which are able to detect obstacles right in front of the user. The Sonic-Guide and the NAVBelt are able to find several obstacles in the environment of the user, too (Nicholas and Sypros, 2003; Roentgen, Gelderblom, Soede, & de Witte, 2008; Roentgen, Gelderblom, Soede, & deWitte, 2009).

The Tactile Acoustical Navigation and Information Assistant (TANIA system) was developed at the Institute for Visualization and Interactive Systems at the University of Stuttgart. It aims to assist visually impaired people in their independent orientation and navigation indoors and outdoors. TANIA consists of a small portable tablet computer and an inertial sensor placed at neck position. The system contains digital maps of the built environment (buildings, streets, etc.) augmented with text information according to the user‘s special needs (Hub, 2010). It calculates the user's position starting from a reference point, for example a radio frequency identification (RFID) tag position, by assessing the user's velocity based on vertical acceleration data. Additionally, this inertial sensor includes a three-dimensional compass and gyroscope. Using the fused sensor data the user's path can be tracked up to step accuracy while walking normally.

However, daily life is not just about undisturbed steps forward. People are stumbling or they walk up- and down stairs (Kramers-de Quervain, 2008). Due to the altered step length on stairways, TANIA would produce a difference of approximately 6 m during ten steps. Given that the system works with the amplitude of acceleration peaks, which occur within every movement, there has to be extra information, e.g., during stair climbing another step length should be assessed compared to walking forward. This requires detection of those special events with the sensors. The challenge is to compare step length and the corresponding velocity and/or acceleration of step patterns with those of straight walking. A reliable algorithm is needed to minimize the error rate of movement detection in order to reduce or even avoid misalignments.

The aim of this study is (1) to find different signal patterns using TANIA sensors in an experimental setup in order to detect different movements often occurring in daily life and (2) to compare the signal patterns of visually impaired compared to non-visually impaired individuals in order to identify significant differences.

2. Materials and methods

2.1. Subjects

Only people with a visual acuity of less than 2% were defined as eligible to take part in the experiment. The subjects were recruited from local sports clubs after contacting the coaches and the subjects were personally informed about the experiments. All visual impaired subjects were blind since birth and are participating in sports activities for several years. The non-impaired group was recruited at the Institute for Sports and Movement Sciences at the University Stuttgart. 16 visually impaired male subjects (age $\underline{M}$ = 40.8 years, $\underline{SD}$ = 18.1 years; height $\underline{M}$ = 178.2 cm, $\underline{SD}$ = 7.4 cm; weight $\underline{M}$ = 76.0 kg, $\underline{SD}$ = 8.9 kg) and 9 visually impaired female subjects (age $\underline{M}$ = 53.4 years, $\underline{SD}$ = 15.8 years; height $\underline{M}$ =164.4 cm, $\underline{SD}$ = 6.9 cm; weight $\underline{M}$ = 67.1 kg, $\underline{SD}$ = 11.4 kg) were included.

For the second step a non-impaired control group with 4 male and 6 female students was included (age $\underline{M}$ = 23.7 years, $\underline{SD}$ = 2.1 years; height $\underline{M}$ = 170.7 cm, $\underline{SD}$ = 4.7 cm; weight $\underline{M}$ = 60.6 kg, $\underline{SD}$ = 4.9 kg). Prior to the subjects' participation in the trial, the written informed consent form, including all potential risk when participating in this study, was read out loud to the visually impaired subjects. An independent witness was present. All subjects gave written consent to participate in this study.

2.2. Measurement

The measurement unit consists of two main parts: (1) A sensing system consisting of one inertial sensor (Fig. 1) and a portable posture monitoring system to record the data and control the sensors.

One inertial sensor (Xsens MTx) worn near C5 (cervical spine) was used during this study. It is a sensor with two different measurement units working with a 3 degrees of freedom (df) Orientation-Tracker. Each sensor module (38 × 53 × 21 mm (W × L × H), 30 g) consists of tri-axial accelerometers, orthogonally aligned, three gyroscopes, also orthogonally aligned, and three magneto-resistive sensors, working as a 3D-compass. There is also a thermometer included (Xsens Technologies B.V., 2009). The inertial sensor was used to monitor the activity profiles of three different movement situations: (A) Stand to Sit/Sit to Stand, (B) Stumble and (C) Stair walking.

The posture monitoring system consists of a portable computer (Sony VAIO©, Sony Cooperation, Tokyo/Japan). The laptop and inertial sensor are connected via a 5 m USB and power cable. The raw data of a_x, a_y, a_z were recorded with the MT-Manager Software for Windows XP/Vista (Hub, 2008) with a recording frequency of 100 Hz. No filters were applied.