The SmartCane System: An Assistive Device for Geriatrics

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ABSTRACT

Falls are currently a leading cause of death from injury in the elderly. The usage of the conventional assistive cane devices is critical in reducing the risk of falls and is relied upon by over 4 million patients in the U.S.. While canes provide physical support as well as supplementary sensing feedback to patients, at the same time, these conventional aids also exhibit serious adverse effects that contribute to falls. The falls due to the improper usage of the canes are particularly acute in the elderly and disabled where reduced cognitive capacity accompanied by the burden of managing cane motion leads to increased risk. This paper describes the development of the SmartCane assistive system that encompasses broad engineering challenges that will impact general development of individualized, robust assistive and prosthetic devices. The SmartCane system combines advances in signal processing, embedded computing, and wireless networking technology to provide capabilities for remote monitoring, local signal processing, and real-time feedback on the cane usage. This system aims to *reduce risks* of injuries and falls by enabling training and guidance of patients in proper usage of assistive devices.

Keywords

SmartCane, real-time sensing and feedback, assistive technology, patient monitoring and feedback

1. INTRODUCTION

Falls have become a leading cause of death from injury in the elderly [13]. Further, the number of elderly individuals with fall-induced injuries is increasing at a greater rate that would be accounted for by demographic changes [11]. A wide range of disabilities and environmental risks contribute to the risk of falling while the disability of age-related cognitive impairments nearly doubles the risk of falling [12]. Injuries due to falls also account for large healthcare costs, for example contributing the major portion of the costs of osteoporosis [9].

Canes provide individuals with biomechanical support for mobility and are used as assistive devices by over 4 million individuals in the United States [8]. Their use is complicated since in addition to physical support, canes provide a sensory input for the user that may contribute to maintaining stability. However, the use of canes also introduces adverse consequences. For example, cane usage introduces an additional cognitive burden to those who suffer from cognitive disability due to age or other causes. The limitations of canes as assistive devices and the potential risk of falling resulting from cane usage arise from multiple factors, including 1) Improper use of canes, 2) Abandoning of the cane (for reasons that may be the result of lack of training), 3) Disorders and disability resulting from repetitive stress, 4) Usage of the cane in the presence of environmental hazards including obstacles, stairs, and surfaces with uncertain support and friction, 5) Disruption of balance due to the competition of attention between cane manipulation and mobility.

This paper describes the development of a new assistive technology that addresses the risks associated with falling and enables the training and monitoring that are recommended as primary interventions [9]. Specifically, the SmartCane system is intended to 1) detect and classify cane usage patterns, 2) predict possible outcomes such as high risk of falling, 3) inform the patient, caregiver, and clinician about the current usage of the cane by a patient, 4) correct usage through education, training, or treatment, 5) provide the research community with technology platforms and data to enable development of assistive technologies for the disabled that combine smart prosthetic devices with the Telehealth architecture [16].

The SmartCane system is developed with low cost, long operating lifetime embedded computing systems. The low-power wireless interface on the SmartCane system permits it to integrate with wearable sensors, standard handheld personal wireless devices, the Internet, and remote services that in the future may include a call center and the medical enterprise. The diverse set of low cost microsensors incorporated into the cane can be used to determine orientation, forces, rotation, which aid in the classification of patient and environment characteristics when combined with other wearable sensor systems on the patient's body.

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In Section 2, we describe the design and implementation of the SmartCane system. In Section 3, we present preliminary data from the SmartCane system. In Section 4, we conclude and outline the future direction of the SmartCane system.

2. MATERIALS AND METHODS

The SmartCane system is implemented with standard, ubiquitous, personal wireless devices to ensure the largest impact and potential for adoption. The following sections describe the hardware and software architecture of the SmartCane system.

2.1 Hardware Architecture

The SmartCane system architecture (as shown in Fig. 1) includes: 1) low cost sensors integrated into the cane measuring motion, rotation, force, strain, and impact signals, 2) embedded computing platforms supporting sensor data acquisition and low power Bluetooth radio interface, and 3) a standard personal device supporting Bluetooth, Wi-Fi, and GPRS interfaces. With the personal device as the master node over the Bluetooth network, the SmartCane system can join other wearable sensors in the MEDIC system and stream its data in real-time to the personal device [16, 14]. The personal device can process the incoming sensor data from the SmartCane system in real-time, provide feedback to the user, as well as forward the data via network access to centralized servers for further development, verification, and optimization.

2.1.1 Sensors

The set of sensors on the SmartCane system consists of a 3-axis accelerometer [1], three single-axis gyroscopes [2], and two pressure sensors [4]. The three gyroscopes are mounted perpendicularly and enclosed in a case near the handle along with the accelerometer. One of the pressure sensors detects the downward force at the cane tip while the other pressure sensor detects the force corresponding to the patient's grip at the handle. The accelerometers and gyroscopes detect the linear acceleration and angular rate of the cane due to the forces exerted by the patient. From these signals, the orientation with respect to the gravity and swing characteristic of the cane can be calculated. Note that the enclosure is designed to follow the contour of the cane in order to minimize the volume taken by these additional electronics. As a result, the cane's reference coordinate system forms a 30° angle with respect to the gravity.

2.1.2 Signal Acquisition

The 16-bit, 0-5 volt data (biased around 2.5 V) from the sensors can be acquired up to 300 samples per second (Hz) and streamed in real-time to a personal device by Bluetooth data acquisition modules [3]; for our application, the signals are sampled at 100 Hz. With eight ADC channels available on each Bluetooth module, the SmartCane system can accommodate up to 16 analog sensors. The Bluetooth sensor nodes form a wireless body area network (WBAN) with the personal device as the master node over the Bluetooth network. Each data point from the Bluetooth module is accompanied by a tracking sequence number to verify errors in Bluetooth communication. With six 2200-mAh AA-size rechargeable batteries embedded inside the cane pole, the Bluetooth sensor modules can stream continuously for over 20 hours.

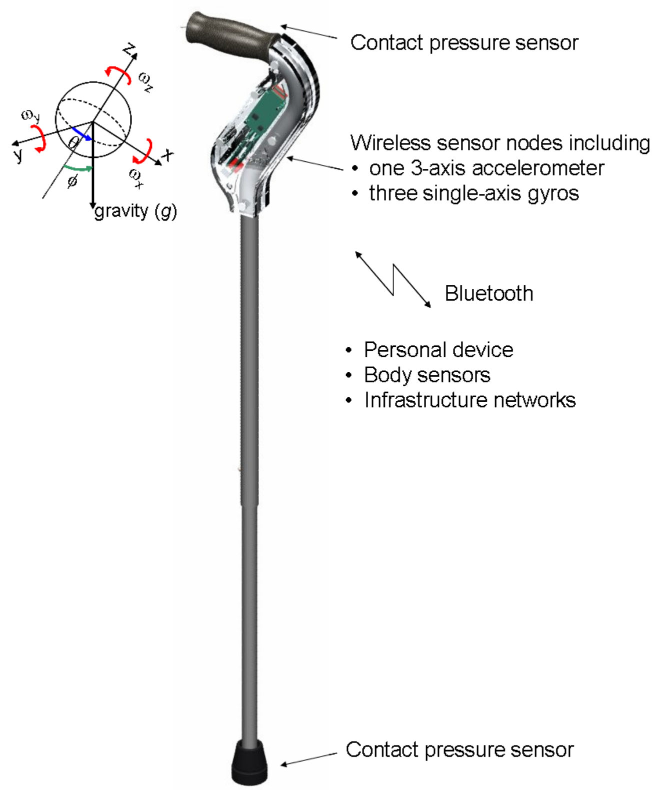

Figure 1: The SmartCane System

2.1.3 Personal Device

Due to the ubiquity of the Bluetooth-equipped devices, the sensor data from the SmartCane system can be streamed to a number of standard personal devices such as cell phones and PDA, or laptop/desktop computers. We interfaced the SmartCane system with a standard PDA [6].

2.2 Software Architecture

The software system on the personal device (Fig. 2) consists of signal processing and inference, graphical user interface (GUI), local data logger, and device server modules [16]. The multi-threaded device server module acquires data from the sensor nodes and forwards to client programs for processing and displaying in real-time. Inside the device server module, a device driver thread handles asynchronous communication to each sensor node over the Bluetooth Serial Port Profile. The device server synchronizes the incoming sensor data before forwarding to the client programs over TCP/IP sockets.

2.2.1 Signal Processing

The inference engine in [14, 15] can be used to detect and classify the patient's usage context of the cane. In this paper, we present the low-pass filtered raw sensor signals to show that these sensor signals can be used to track the cane's orientation, motion and rotational forces. This accurate state information about the cane permits the care givers to monitor the patient's usage pattern of the cane and create the feedback model to train the proper usage of the cane [10].

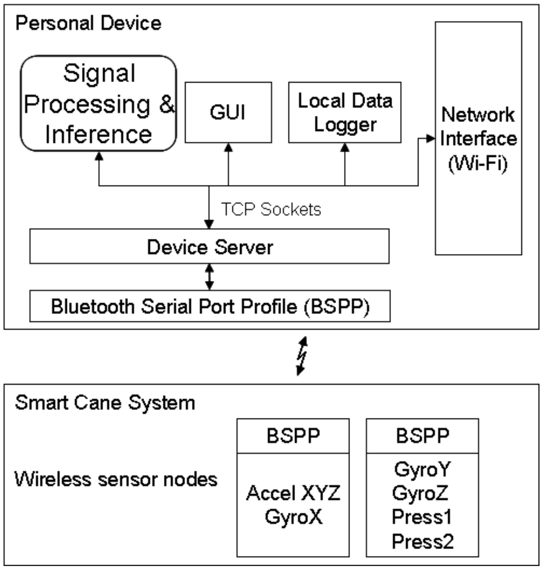

Figure 2: Software Architecture

2.2.2 *Experimental System Display and Analysis*

The user feedback of the cane usage is accomplished via the graphical user interface (GUI) screen on the PDA, as shown in Fig. 3. The GUI is implemented using the GTK+ toolkit in the Maemo development framework [5], which also permits the same GUI software to run on a standard computer. The raw sensor signals and the signal processing/inference output can be viewed on the GUI in real-time. In addition, the activation/deactivation of the sensor nodes can be controlled from the GUI.

3. RESULTS

The preliminary results from the SmartCane system are shown in Fig. 4. The raw data streaming from the cane system was saved on the personal device during a 35-second long experiment in which a patient was performing daily activities such as holding the cane, slow walk, fast walk, turning 90 degrees, and turning 180 degrees.

We converted the 3-axis accelerometry information in 3-dimension Cartesian coordinate system to 3-dimension polar coordinate system. Fig. 4-a shows the magnitude of the resultant acceleration vector on the cane system which includes the acceleration due to the gravity g and the acceleration caused by external forces on the cane. This magnitude and its periodicity correspond well with the intensity of walking motion. The two angles that define the resultant acceleration vector are shown in Fig. 4-b and -c. Due to the fact that the SmartCane system's reference coordinate system is tilted 30 degrees (Fig. 1), the tilt angle ϕ fluctuates around the 30-degree mark. The tilt angle θ shows how the cane is tilted to one side (towards or away from the patient body) during walk. In this case, θ is consistently in the negative (leaning left), which may be due to the fact that the patient is holding the cane on the right side.

The swing characteristics of the cane during walking can be seen in Fig. 4-d, which shows *pitch* angular velocity ω_y. Note that this rate of change of the tilt angle corresponds with the slope of the tilt angle ϕ in Fig. 4-b. Because the

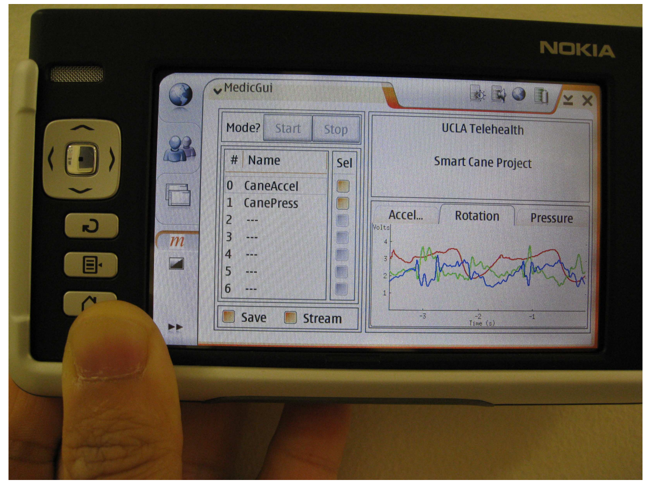

Figure 3: Experimental system display and analysis on a PDA screen.

reference coordinate system on the cane is tilted, both *yaw* (ω_z) and *roll* (ω_x) gyroscopes, Fig. 4-e and -f respectively, detected the patient's change of direction.

Finally, the two pressure sensors in Fig. 4-g and -h detect the magnitude of the contact forces at the tip and handle, respectively. Although the accelerometer signals can detect the fact that the cane hits the ground, these pressure sensors can be calibrated in order to measure the forces exerted by the patient more accurately.

4. CONCLUSION & FUTURE WORK

In this paper, we presented the design and development of the SmartCane system that utilizes the capabilities provided by the Telehealth architecture, which may be based on commercially available microsensor, computing, and wireless technologies. We also presented preliminary data from a patient using the SmartCane system and showed that the data can be used to analyze the patient's usage of the cane. Combined with the MEDIC Telehealth system [16], the SmartCane system can transport this data from the patient's home to the centralized servers in the medical enterprise, permitting caregivers to monitor the cane usage in real-time and over long periods. This will enable future applications where patients are actively guided towards safe behavior, thereby reducing the risk of falls.

Our future work to further develop the SmartCane system includes several objectives. First, we plan to characterize the cane usage patterns across a large group of patients and develop statistical models that can identify and detect the improper usage behavior leading to instability and falls in the elderly. We plan to use these statistical models to guide and train these elderly patients to properly use the cane [10]. Second, we plan to expand our sensor set to measure the foot balance and the joint angle on the arm holding the cane. These new on-body information sources can help in developing the proper usage model of the cane. Finally, we plan to incorporate the energy-aware capability provided by the MicroLEAP sensor platform [7] in the SmartCane system to further extend the operating battery life time of this system to well over a day of usage cycle.

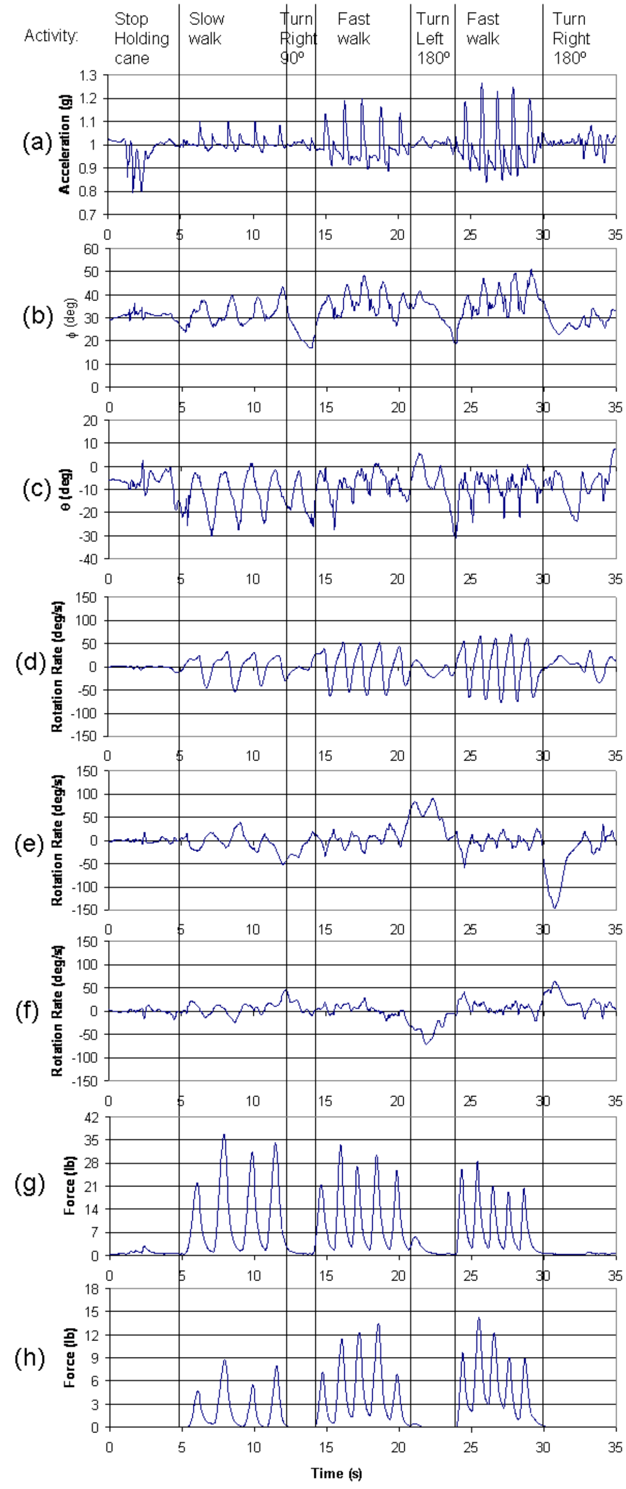

Figure 4: Data from the SmartCane system during patient activities. (a) Magnitude of acceleration relative to the gravity *g*, (b) Tilt angle ϕ respect to the z-axis, (c) Tilt angle θ respect to the x-axis, (d) *Pitch* angular velocity ω_y, (e) *Yaw* angular velocity ω_z, (f) *Roll* angular velocity ω_x, (g) Force at the cane tip, and (h) Force at the cane handle.

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