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Real-time monitoring of elderly using their connected walking stick

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Abstract—Lots of aging people rely on a cane as an assistive device to avoid problems such as leg weakness and balance loss, which are presumed to have induced many fall incidents. In this paper, we present a new design and implementation of Canne3D system, a local monitoring system for elderly using their connected walking stick. Actually, the 3D cane is modeled through consideration of real-time movements for a deep understanding of the person's state, including steps counting and calculating the distance traveled. We have applied a simple multi-stage thresholding method based on the acceleration value. Experiments show that the algorithms appear to be robust in term of detection rate and false positive rate.

Keywords—*m-Health; Thresholding; Accelerometer; Magnetometer*

I. INTRODUCTION

The Internet of Things (IoT) is the future Internet; it represents a revolution in computing and communications. It enables a world of networked devices, where everything is interconnected and has a virtual representation [1]. Everyday objects are transformed into smart objects able to sense, interpret and react to the environment thanks to the combination of Internet and emerging technologies such as Radio-frequency Identification (RFID), real-time localization and embedded sensors [2].

We strongly believe that the Internet of Things can give the assistance and support to people with disabilities that they need to achieve a good quality of life and allows them to participate in the social and economic life. Assistive IoT technologies are powerful tools to increase independence and improve participation. Real-time monitoring systems will be increasingly useful and necessary in the coming years. The population is aging and the society must solve this new problem and find the best way to take care of elderly [3]. Therefore, mobility devices and personal assistance are strongly desired to ensure a certain independence of the elderly. Possible assistance devices include canes that have a large number of older users because of their simplicity and walking aid they bring.

This paper proposes a contribution for the 3DCane system [4], which is a system that tracks the movements of elderly more visually using their walking stick. This system allows

the display of a 3D model of the cane and its graphic animation based on actual movements obtained through a wireless transmission of data from sensors on the cane (accelerometer and magnetometer), it also counts the number of steps and calculates distance in meters.

The following article is organized as follows: Section 2 provides an overview of 3DCane system, including the hardware and software architectures. In Section 3, we offer to present the design and details of 3D sensing and modeling algorithms that we have developed, which are next evaluated experimentally in terms of detection rate and of false positive rate in Section 4. Finally, in section 5, we conclude the whole paper and we give an idea of the possible future improvements and extensions of 3DCane system.

II. SYSTEM ARCHITECTURE

Faced with an aging population and the massive use of the walking cane by the elderly, researchers from Toulouse-Blagnac have created the CANet project [5] which is a system for monitoring people with disabilities through their walking cane. Our monitoring system is based on the CANet project, Figure 1 shows the architecture of 3DCane system that we have developed. The system consists of: (i) a transmitter node positioned on the cane, (ii) a receiver node and (iii) a terminal for data analysis and 3DCane application.

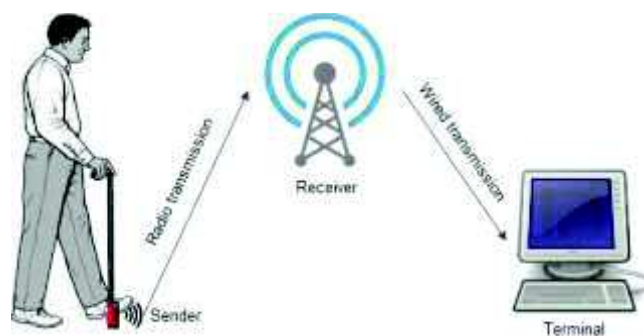


Fig. 1. 3DCane System architecture

A. The transmitter

The transmitter node is used (i) to collect data from the 3D accelerometer and 3D Magnetometer, (ii) calculate the linear

acceleration and acceleration due to gravity, (iii) calculate the angle of rotation on x-axis (roll), the rotation angle on the y-axis (pitch), the rotation angle on the z-axis (yaw), (iv) fall detection, calculate the number of steps and the distance traveled, and (v) ensure the transmission of data.

For this sake, we used an lsm303dlhc which is a system-in-package featuring a 3D digital linear acceleration sensor and a 3D digital magnetic sensor, a Teensy 3.2 as a processingboard and a Radio RFM22 used for data transmission, the node architecture is explained in figure 2.

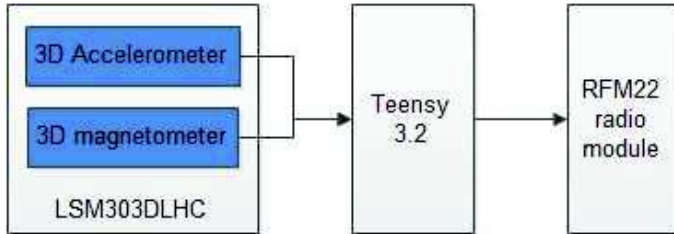


Fig. 2. Sender node composition

The LSM303DLHC has linear acceleration full-scales of $\pm 2g / \pm 4g / \pm 8g / \pm 16g$ and a magnetic field full-scale of $\pm 1.3 / \pm 1.9 / \pm 2.5 / \pm 4.0 / \pm 4.7 / \pm 5.6 / \pm 8.1$ gauss. All full-scales available are fully selectable by the user [6]. The Teensy 3.2 has a MK20DX256 Processor, 32 bit ARM, Cortex-M4, 72 MHz. Flash Memory: 262144. RAM Memory: 65536. EEPROM: 2048. The RFM22 has a Frequency Range between 240 MHz and 930 MHz, a sensitivity of -118 dBm, a data Rate from 1 to 128 kbps, a $+17$ dBm Max Output Power and a power supply of 1.8 V to 3.6 V.

B. Communication protocol

The architecture we proposed is composed of multiple transmitters (cane) that send data to one receiver for local monitoring, so we used aloha as a medium access protocol. The RFM22 radio module uses the 802.15.4 norm for packet format. The MAC frame format is composed of a MHR, a MAC payload, and a MFR as represented in figure 3.

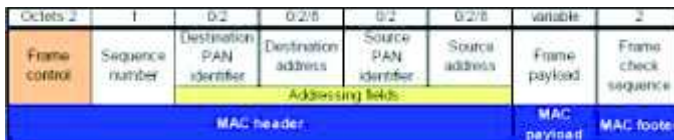


Fig. 3. MAC frame

For transmission we used a frequency that belongs to an ISM (Industrial, Scientific and Medical) 411 Mhz .ISM bands [7] are frequency bands that can be used in a small space for industrial, scientific, medical, domestic or similar.

The slot time used is 100 ms to enable better monitoring in real time. Frame payload is represented in table 1.

TABLE I. DATA COMPOSITION

Name	Description	Size
CaneId	unique identifier of the cane	16
Roll	Rotation angle on the x axis	32
Pitch	Rotation angle on the y axis	32
Lx	Linear acceleration on the x-axis	32
Ly	Linear acceleration on the y-axis	32
Lz	Linear acceleration on the z-axis	32
Gx	Acceleration due to gravity on the x axis	32
Gy	Acceleration due to gravity on the y axis	32
Gz	Acceleration due to gravity on the z axis	32
Pas	Number of steps	16
Yaw	Rotation angle on the z axis	32
Distance	Distance traveled	16
Fall	Boolean indicating if a fall is detected	1

The message size is 337 bits therefore message transmission time is 0.81ms.

III. METHOD

In this section, we will detail the algorithms of functioning of our Cane3d system such as the determination of absolute orientation, the algorithm of steps counting and calculate the distance traveled.

X, Y and Z axes of the acceleration are represented on the cane in the following manner as shown in Figure 4.



Fig. 4. representation of X, Y and Z axes.

A. Absolute orientation

To determine the orientation of cane, it is necessary to calculate the angle of rotation on the x-axis (roll), the rotation angle on the y-axis (pitch) and the rotation angle on z axis (yaw) as shown in Figure 5.

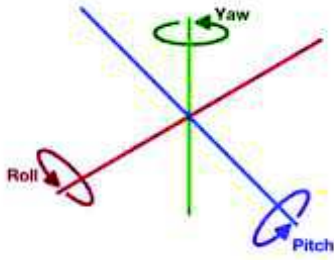


Fig. 5. Rotation on x, y and z axes.

The accelerometer is intended to provide a measurement based on the linear acceleration and acceleration due to gravity [8]. Still, a major problem related to the accelerometers consists in the fact that they help measure both of the linear acceleration and that related to gravity. As it cannot distinguish between these two accelerations, it turns out to be critically necessary to separate both of the acceleration types (gravity and motion) through the use of a special filter.

On the X axis, for instance, the gravity relating acceleration can be calculated as follows:

Initially $Xg = 0$.

$$Xg = X * \alpha + (Xg * (1 - \alpha)) \quad (1)$$

With $\alpha = 0.5$ (as presented in [9]) and X is the value of acceleration on the x-axis provided by the accelerometer.

Using the accelerometer output, the rotation around the X axis (roll) and the Y axis (pitch) can actually be calculated. On considering the Accel_X, Accel_Y and Accel_Z as the accelerometer measurements (gravity acceleration) in the X, Y and Z, then equations (2) and (3) below, would demonstrate how to calculate the angles Roll and Pitch [10]:

$$Pitch = \arctan\left(\frac{Accel_X}{\sqrt{(Accel_X)^2 + (Accel_Z)^2}}\right) \quad (2)$$

$$Roll = \arctan\left(\frac{Accel_Y}{\sqrt{(Accel_Y)^2 + (Accel_Z)^2}}\right) \quad (3)$$

If m_x , m_y and m_z are calibrated and normalized magnetometer outputs, and α , β and γ respectively stand for roll, pitch and yaw, the heading appears to be computable through equation (6). Equations 4 and 5 are applied to transform the magnetometer reading to the horizontal plane. Once the magnetometer data appear on the flat plane, equation 6 would then get a reliable calculation.

$$XH = m_x \cos(\beta) + m_y \sin(\beta) \sin(\alpha) + m_z \sin(\beta) \cos(\alpha) \quad (4)$$

$$YH = m_y \cos(\alpha) + m_z \sin(\alpha) \quad (5)$$

$$\gamma = \text{atan2}\left(\frac{-YH}{XH}\right) \quad (6)$$

B. Steps counting

We can use the linear acceleration to determine if the person is walking using his walking stick by observing the change of the linear acceleration in the X, Y and Z as shown in Figure 6.

When an elderly person is walking with his cane, the acceleration value due to gravity on the y-axis remains above 9 m/s.

After analyzing the changes in linear acceleration and acceleration due to gravity we implemented an automatic step detection algorithm:

```

Steps = 0.
Count = 0.
Store the 3 oldvaluesoflinear
accelerationonthe z axisin the
variablesLZ1, LZ2andLZ3.
If (ly>0.5) and (Iz>0.5
orLZ1>0.5orLZ2>0.5orLZ3>0.5) and (gy>9) and
(count == 0) then
steps++
Count =5
Endif.
If(count > 0) then
Count = Count - 1.
EndIf.

```

Ly is the linear acceleration on the y-axis and gy is the acceleration related to the gravity of the y axis. The minimum period between steps of a person is equal to 0.5 seconds. For this, we added a counter variable to not confuse one step to another activity.



Fig. 6. Detection of a step through the linear acceleration.

C. Distance traveled

The distance is relative to the movement of the Cane on the z axis. In fact, when the person walks with his cane, the

acceleration on the z-axis increases and then decreases and then returns to 0. This is the same reasoning for calculating the number of steps.

In general, to calculate a distance from the acceleration, we have to use the following rule:

If we consider $a = \text{constant acceleration during a time } t$ then:

$$\text{Speed } v(t) = a * t + v_0; \text{ with } v_0 = \text{initial speed};$$

$$\text{Distance } s(t) = \frac{1}{2} * a * t^2 + v_0 * t;$$

In our case $t = 100 \text{ ms}$, and we calculated the speed and distance traveled each time a step is detected.

IV. RESULTS AND PERFORMANCE ANALYSES

In a first test, we evaluated the GUI of the application in many situations then we performed the test of the fall detection algorithm and the calculation of the number of steps and distance traveled.

A. The GUI

The 3DCane GUI resulting application allows a visualizing of the real time Cane status using a 3D display representing its absolute orientation. It also helps recognize the number of steps and the traveled distance. It helps also recognizing the direction of the cane (North, East, West, and South) like in figure 7.

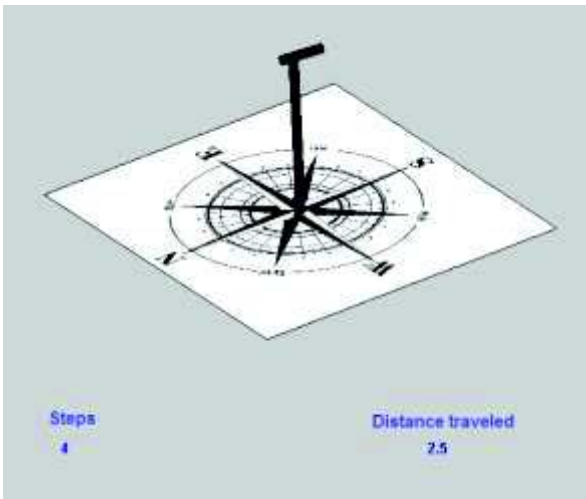


Fig. 7. GUI Cane3d application

The cane 3D modeling, together with its movements, appears to be helpful in identifying its condition as well as the user's status. Once a fall is detected, the application triggers a voice alert as shown in figure 8. In addition, such an interface enables us to recognize whether the user is walking or in a standing still position.

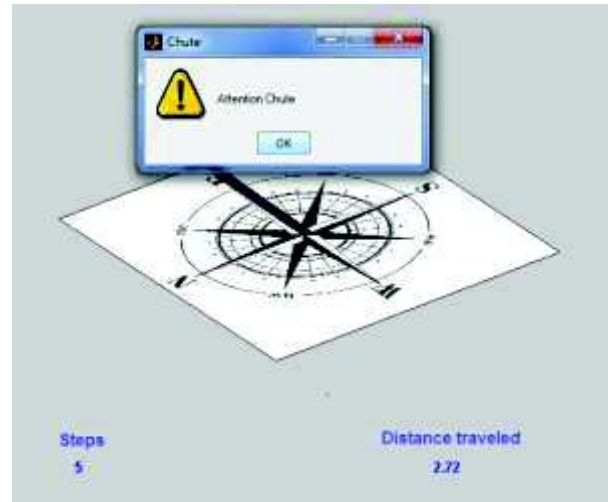


Fig. 8. GUI Cane3d application when falling with the cane

B. Steps counting

For the test of the steps counting algorithm; we have chosen four different people. Each one of those persons have made 100 meters of walking and then we have measured the distance given by the application.

TABLE II. AVERAGE STEPS MEASURED FOR 100 STEPS TAKEN BY FOUR PERSONS

Walk types	Result
Slow walk	96
Fast walk	94

Table 2 shows that with a slow walks or fast walk, the number of detected steps is almost the same as the number of steps made by the four persons.

TABLE III. FALSE POSITIVE RATE FOR VARIOUS ACTIVITIES

Activity	Percentage
Fall	0%
Swing	5%
Sit and stand	5%
Lay on lap	0%

Table 3 reveals well that steps detection algorithm is robust since the false positive rate is almost equal to 0 for various activities.

C. Distance traveled

We have also chosen four different people in order to test the measurement of the distance traveled, results are shown in the next table.

Table 4 shows that the algorithm of calculation the distance is efficient, in fact the average error doesn't exceed 6% so the measured distance can be used to monitor the elderly.

TABLE IV. DISTANCE MEASURED FOR 100 METERS OF WALKING

Person	Result (m)
1	105
2	106
3	103.7
4	104.2

V. CONCLUSION

In this work, we have developed a novel method for real-time monitoring of disabled people, using their walking cane equipped with an accelerometer and a magnetometer. We implemented an algorithm for calculating the steps number and the distance traveled, and then we implemented the 3DCane application, to visualize the state of the walking stick in real-time and to control the elderly movement. Experimentations show that Canne3d application is efficient and useful for elderly monitoring.

As the current application can be used for local monitoring, we plan to extend our work and enable the monitoring via the internet.

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