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A signal processing algorithm for improving the performance of a gyroscopic head-borne computer mouse

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ABSTRACT

This paper presents a signal processing algorithm to remove different types of noise from a gyroscopic head-borne computer mouse. The proposed algorithm is a combination of a Kalman filter (KF), a Weighted-frequency Fourier Linear Combiner (WFLC) and a threshold with delay method (TWD). The gyroscopic head-borne mouse was developed to assist persons with movement disorders. However, since MEMS-gyroscopes are usually sensitive to environmental disturbances such as shock, vibration and temperature change, a large portion of noise is added at the same time as the head movement is sensed by the MEMS-gyroscope. The combined method is applied to the specially adapted mouse, to filter out different types of noise together with the offset and drift, with marginal need of the calculation capacity. The method is examined with both static state tests and movement operation tests. Angular position is used to evaluate the errors. The results demonstrate that the combined method improved the head motion signal substantially, with 100.0% error reduction during the static state, 98.2% position error correction in the case of movements without drift and 99.9% with drift. The proposed combination in this paper improved the static stability and position accuracy of the gyroscopic head-borne mouse system by reducing noise, offset and drift, and also has the potential to be used in other gyroscopic sensor systems to improve the accuracy of signals.

1. Introduction

Micro-electro-mechanical system (MEMS) sensors are widely utilized in many different areas like automobiles, consumer electronics, spacecraft and robotics since they are of relatively small size, low weight, low power consumption and low price [1]. In connection with the growth of eHealth, many wearable healthcare applications based on MEMS-sensors have been presented, such as human motion tracking for rehabilitation by Zhou et al. in 2006 [2] and 2008 [3], fall detection by Nyan and et al. in 2008 [4], Chang et al. in 2011 [5], Baig et al. in 2013 [6] and Chen et al. in 2015 [7], activity tracking and recognition by Jovanov et al. in 2011 [8] and Li et al. in 2015 [9], and artefact reduction by O'Regan et al. in 2013 [10].

A MEMS-gyroscope based head-borne computer mouse system called MultiPos, was developed previously with the aim of helping people with movement disorders [11]. It enables the users to control the cursor by moving their heads. As shown in Fig. 1, the MultiPos system is composed of three parts: one wearable head band with MEMS-gyroscope, one main controller part with microprocessor, and one click function part which can be substituted by a sip-and-puff device, a click device or a biting device, rendering it adaptable to the needs of different users.

The signal, collected from a MEMS-gyroscope, is largely influenced by noise, since the gyroscope is sensitive to environmental disturbances, such as shocks, vibrations and changes in temperature. Based on the investigated common sensor errors and the MultiPos system, the signal problems of the MultiPos system can be classified as noise, offset and drift. Noise includes shocks, vibrations, human tremor, electrical noise and mechanical thermal noise, etc. Offset is defined as the constant output error with zero input. Drift has two main classifications, null drift and temperature drift. Temperature changes, acceleration and hysteresis are common causes of drift.

A Microchip® digital signal controller (dsPIC®) is used in the MultiPos system as a slave processor as it includes signal processing. One important hardware limitation in the MultiPos system is

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Fig. 1. The MultiPos system. From left to right: pink click device, communication part in a black box, head band with built-in MEMS gyroscope. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

limited calculation capacity in real time. Thus, the signal processing is focused on noise reduction, offset/dead zone, drift minimization, and signal stability. It is, therefore, concluded that the signal processing algorithms in the MultiPos system must be able to minimize signal errors and improve the signal quality; be simple enough and comply with the system requirements; and be compatible for application with different MEMS-gyroscopes.

Several signal processing algorithms have been developed and applied to the MEMS-gyroscopic head-borne mouse system with the aim of addressing the various signal problems. A low-pass filter (LPF), a Least Mean Square algorithm (LMS), a Kalman filter (KF) and a Weighted-frequency Fourier Linear Combiner (WFLC) were implemented individually and the results were compared with the intention of reducing noise [12]. A high-pass filter (HPF), LMS and KF were used individually for the reduction of temperature drift [13]. These algorithms were all applied to the head-borne computer mouse and the results showed that these algorithms could be used to improve the MEMS-gyroscope signal. In addition, the signal processing algorithms were readily implemented into the MultiPos system with its existing hardware limitation in real time. The Kalman filter showed its superiority in the reduction of temperature induced drift in the MultiPos system [13], while WFLC filter was the most suitable for the reduction noise in the MultiPos system [12]. However, a simple and efficient method to improve the MEMS-gyroscope signal with the errors of noise, offset and drift together, especially on static stability and position accuracy, is desired.

With the aim of addressing similar problems to those outlined above, various signal processing algorithms have been applied in other wearable systems and human–machine interfaces. For example, a master-slave Kalman filter was proposed to predict the heart motion for robot assisted surgery [14], the WFLC/FLC can be used to cancel pathological tremor in graphical user interfaces, providing smooth cursor control for mice, joysticks and pens [15], the bandlimited multiple Fourier Linear Combiner (BMFLC) can effectively remove physiological and pathological tremor [16,17], and a variable threshold method has been used to detect ECG R-peaks in a wearable ECG monitoring system [18].

In the application of the MEMS-gyroscopic head-borne computer mouse, it is very important to keep the cursor stable during the static state, both before and after the movements, to obtain an accurate position. The combination of a Kalman filter, WFLC and threshold with delay method (TWD) is presented in this paper with the aim of improving the static stability and position accuracy of the system by reducing noise, offset and drift simultaneously. The total execution time is sufficiently small for the users not to perceive any system delay.

2. Method

2.1. Instrument

During the test, the sensor part of the MultiPos system is connected with the main controller part by cable. In turn, the main controller for the MultiPos system is connected to a computer by two USB-ports. One of these is used for the power supply of the system and for cursor movement connection. The other is used for the data recording via a Universal Asynchronous Receiver/Transmitter (UART). The test computer was a Lenovo® E420s and the operation system was Microsoft Windows® 10. Implementation was done with MPLAB® in C code. The output data from the MultiPos system was saved in the form of hexadecimal numbers in a txt-file as x and y-coordinates, respectively with a baud rate of 57,600. The sampling frequency was 50 Hz. Room temperature was around 21 °C.

The software, named HyperTerminal®, was used to show and save the data from an UART pin of the dsPIC to the computer. With the port settings of baud rate (57,600), data bits (8) and stop bits (1), the recording of the data of the MultiPos system can be shown and saved in a.txt file.

2.2. Data preparation

The experimental test is classified into two different situations. Situation one focuses on signal improvement with respect to noise, offset and drift in a stationary state situation over a relatively long time period, approximately one and a half hours. The second situation focuses on how movement affects the signal and system. The test equipment, called Test Rig [19], can provide a fixed movement pattern and also simulate human movements. The Test Rig was used to test different movement patterns under different environmental conditions by changing the temperature and subjecting the system to vibration. MEMS-gyroscopes often have unique behavior and characteristics. Thus, the test was performed with three different MEMS-gyroscopes using the same test set-ups. The MEMS-gyroscopes were IDG300, MLX90609 and L3G4200D. IDG 300 is an integrated dual-axis angular rate sensor (gyroscope) from InvenSense®. It can be used in many applications where low cost, small size and high performance are required, for example, in Inertial Measurement Units (IMUs), handheld GPS navigation devices, and robotic and power tools [20]. In the real test we subjected IDG300 to in our system, it exhibited significant temperature-inducted drift [13]. MLX90609 is an angular rate sensor from Melexis®. Its features are low acceleration and angular rate cross sensitivity and low zero-rate output drift [21]. L3G4200D is an ultra-stable triple-axis digital output gyroscope from STMicroelectronics®. It is a low-power MEMS motion sensor [22]. The detailed description of the tests follows below:

1). Static state 85 min. The MultiPos system at room temperature was positioned on the table and connected to the computer, and left immobile for 85 min. The purpose of this test was to investigate the stability of the system in a stationary operating situation.

2). Movement operation 65 s. The MEMS-gyroscope was fixed on the Test Rig and moved by pre-defined movements of the Test Rig in a slow mode (up to 15 °/s) that simulates a movement made by a motion disabled person. The test was performed from a stationary state to movement and then back to a stationary state without and with large drift, respectively. The IDG300 and MLX90609 were used since they showed the largest and smallest offset and drift (worst and best case) as shown in Fig. 3. The large drift was accomplished by changing the temperature. To simulate large drift, the room-temperature (21 °C) MEMS-gyroscopes MLX90609 and IDG300 were put into a freezer (−18 °C) for about 5 min and then tested in the room-temperature environment. The movement