HARDWARE-SOFTWARE COMPLEX FOR OBTAINING AND ANALYZING EXPERIMENTAL DATA

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ПРОГРАММНО-АППАРАТНЫЙ КОМПЛЕКС ДЛЯ ПОЛУЧЕНИЯ И АНАЛИЗА ЭКСПЕРИМЕНТАЛЬНЫХ ДАННЫХ

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ABSTRACT

This paper explores the hardware design of an STM32-based data acquisition system with BMP180 and MPU-6050 sensors. It emphasizes the use of sensor data filtering and introduces the Kalman filter for effective sensor data fusion. Additionally, it investigates the applications of Convolutional Neural Networks (CNN) in pattern recognition and motion activity classification.

АННОТАЦИЯ

В данной работе исследуется аппаратное проектирование системы сбора данных на базе STM32 с использованием датчиков BMP180 и MPU-6050. Особое внимание уделяется фильтрации данных датчиков и представлению фильтра Калмана как эффективного метода слияния данных датчиков. Кроме того, исследуются возможности применения сверточных нейронных сетей (Convolutional Neural Networks, CNN) в распознавании образов и классификации движений.

Keywords: embedded systems, sensor fusion.
Ключевые слова: встраиваемые системы, слияние данных датчиков.

Introduction

Motion of objects is a fundamental concept in physics that studies the changes in position and state of objects in space over time. This phenomenon surrounds us everywhere– from the motion of planets around the Sun to the movement of cars on roads, from the motion of the human body to the motion of electrons in atoms. Experimental methods are widely used to achieve a deep understanding of this concept. Experiments focused on the study of motion play a crucial role in scientific research, enabling us to test hypotheses, establish patterns, and obtain precise quantitative data.

In this context, the present work aims to implement a comprehensive hardware-software system for motion tracking using the STM32 microcontroller, BMP180 sensor, and MPU6050 sensor.

The STM32 microcontroller serves as the core component of the system, providing the necessary computational power and control capabilities. It facilitates the integration of multiple sensors and enables real-time data acquisition and processing. The BMP180 sensor, based on barometric pressure measurement, provides accurate altitude information, while the MPU6050 sensor, a combination of accelerometer and gyroscope, offers precise motion sensing capabilities. By combining the data from these sensors, the system can effectively capture and analyze the motion characteristics of physical objects.

The developed solution can be used to track motion of various objects for different purposes. This tool can be helpful for researchers, college and school students for exploring the laws of motion and tracking device movements.

Hardware design of STM32-based data acquisition system

STM32 is a family of microcontrollers developed by STMicroelectronics [1]. It is based on the ARM Cortex-M processor architecture, which provides a powerful and energy-efficient platform for various embedded applications.

STM32 microcontrollers find applications in a wide range of industries, including consumer electronics, industrial automation, automotive, healthcare, Internet of Things (IoT), and more. Their versatility, performance, and extensive ecosystem make them a popular choice for embedded system development.

MEMS (Micro-Electro-Mechanical Systems) are miniature devices that combine microelectronics with mechanical elements to enable the sensing, actuation, and control of physical phenomena on a microscale [2].

MPU-6050 is a widely used 6-degree-of-freedom (6DoF) motion tracking sensor. The MPU-6050 combines a three-axis accelerometer and a three-axis gyroscope in a single chip, enabling accurate measurement of both linear acceleration and angular velocity. It also includes an onboard Digital Motion Processor (DMP) that performs complex motion processing and sensor fusion algorithms, simplifying the integration and interpretation of motion data.

BMP180 is a digital barometric pressure and temperature sensor developed by Bosch Sensortec. The sensor is based on piezo-resistive technology, which allows for accurate and reliable measurements of barometric pressure and temperature. It provides a digital output interface, making it easy to integrate with microcontrollers such as the STM32.

In the field of activity recognition, studies have shown that the inclusion of a barometer as part of the sensor suite can significantly improve the recognition of vertical dynamic activities (VDAs), which are critical in many applications [3]. While accelerometers are still the predominant sensors used in activity recognition, the addition of a barometer enhances the accuracy of recognizing activities such as walking, distinguishing between different modes of vertical transportation (e.g., stairs, elevators, escalators), and detecting falls.

Sensor data filtering

Filtering sensor data is a crucial step in extracting meaningful information and improving the accuracy of measurements. Sensor data often contains noise, outliers, and artifacts that can distort the true underlying signals. Filtering techniques aim to remove or mitigate these unwanted elements while preserving the essential features of the data.

The Kalman filter is a widely used recursive estimation algorithm that combines measurements with a mathematical model of a system to produce optimal estimates of the true underlying state variables. It is particularly effective in situations where there is uncertainty in measurements and where the system dynamics can be described by linear equations. The result of filter application is shown on Figure 1.

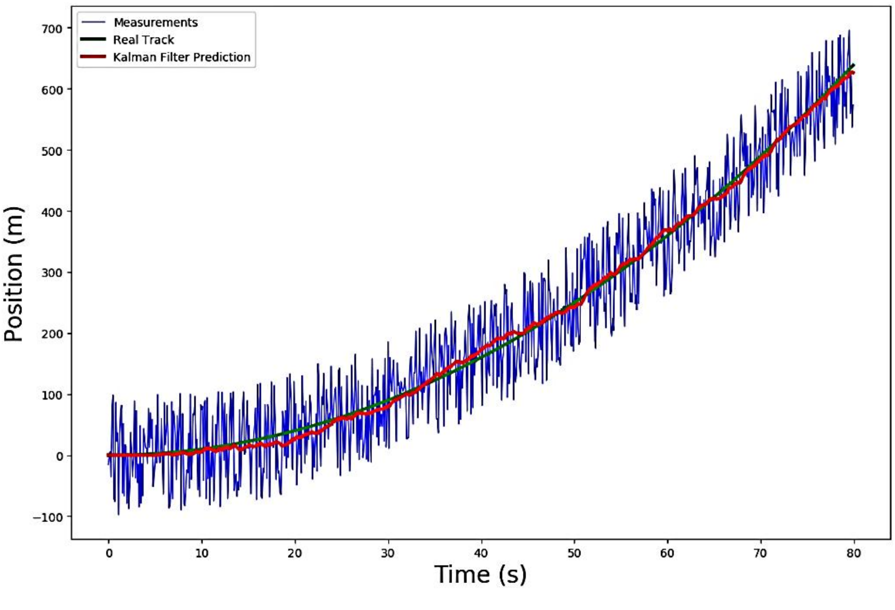

Figure 1. Kalman filter application example

The Kalman filter operates in a two-step process: the prediction step and the correction step. In the prediction step, the filter uses the system model and the previous estimate to predict the current state and its covariance. It accounts for the system's dynamics, taking into consideration factors such as motion, noise, and disturbances.

In the correction step, the filter incorporates measurements from sensors to update the state estimate and its covariance. It compares the predicted measurement based on the estimated state with the actual measurement and adjusts the state estimate based on the difference between the two. The filter also considers the uncertainties associated with the measurements and the estimated state to determine the optimal update.

The Kalman filter employs two key mathematical equations: the state prediction equation and the measurement update equation. The state prediction equation represents the system dynamics and predicts the current state based on the previous estimate. The measurement update equation combines the predicted state with the measurement to update the state estimate, taking into account the covariance of the measurements and the state.

The Kalman filter is an algorithm commonly employed for sensor fusion to estimate altitude by combining data from an Inertial Measurement Unit (IMU) and a barometer. It serves as a state estimator, integrating the measurements from both sensors to provide more accurate altitude estimation. By incorporating the barometer alongside the IMU-based attitude estimation, the proposed method aims to enhance the overall results. Specifically, the method utilizes IMU sensors and an Extended Kalman Filter (EKF) to estimate attitude, utilizing the linear vertical component of acceleration in conjunction with barometric data [5].

Classifying motion activity type using convolutional neural network

Motion type detection is a valuable application of Convolutional Neural Networks (CNN). By utilizing CNN, it is possible to automatically classify and detect various types of motion based on input sensor data [6].

CNN excel at learning complex patterns and features from input data. By training a CNN on a dataset comprising different motion types, such as walking, running, jumping, or dancing, the network can learn to automatically recognize and classify these motions. This eliminates the need for manual feature extraction and enables efficient and accurate detection.

CNN are designed to extract meaningful features from input data. In the context of motion type detection, the network learns to identify distinctive patterns and motion characteristics that differentiate one type of motion from another. This allows for robust and reliable motion classification, even in the presence of noise or variations in the input data.

CNN are capable of generalizing from training examples to classify unseen instances. Once trained on a diverse dataset, the CNN can effectively classify various motion types, even those it has not encountered during training. This scalability and generalization enable the detection of a wide range of motion types without the need for extensive manual labeling or training for each specific motion type.

Conclusion

In summary, the hardware design of an STM32-based data acquisition system, combined with MEMS modules, sensor fusion techniques, sensor data filtering, and data processing using neural networks, provides a comprehensive approach to developing advanced embedded systems. These systems can be utilized across a wide range of applications, including activity recognition, environmental monitoring, and motion detection, ultimately contributing to improved accuracy, reliability, and efficiency in data acquisition and analysis.

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