Sensor data compression and power management scheme for low power sensor hub

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Abstract: This paper proposes a sensor data compression mechanism based on the amount of change of sensor input data and a power management scheme for various sensors used for the motion recognition application. The experimental results confirmed that the proposed compression mechanism and power management scheme reduced the wakeup count of the sensor hub core and the amount of data transmitted to the core by about 78% compared to the conventional data buffering structure, and the power consumption of the IMU (inertial measurement unit) is reduced by about 56%.

Keywords: sensor hub, low-power sensing, motion recognition

Classification: Integrated circuits

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1 Introduction

Recently, as the use of wearable devices due to the arrival of the Internet of Things (IoT) era has been increasing, many IoT devices for performing motion recognition have become popular [1, 2]. These devices require high accurate motion recognition, with very low power consumption due to the small capacity battery of the devices. Various sensors such as gyroscope in addition to accelerometer are used to improve recognition accuracy. However, the use of multiple sensors causes an increase in power consumption. Therefore, IMU manufacturer provides a function to switch certain sensors to sleep mode [3, 4, 5]. However, switching the sensor to the sleep mode without careful consideration can hurt the accuracy of motion recognition.

This paper proposed a sensor data compression and power management scheme to compress the sensor data and stopping the operation of the highly power consumption sensor when the change of sensor input data is continuously small. The experimental results confirmed that the wakeup count of the sensor hub core and the amount of sensor data transmitted to the core are reduced by about 78% compared to the conventional sensor data buffering structure, and the power consumption of the IMU is reduced by about 56% with the proposed compression and power management scheme.

2 Related work

Various studies have been performed to reduce the power consumption of the sensor hub and the sensors attached to it [6, 7, 8].

In [6], all sensor data are collected in the rate of the fastest sampling rate among the sensors to reduce the wakeup frequency to collect the input sensor data from sensors with different sampling rate. A sensor data buffering scheme proposed in [7] stores sensor data for reducing the number of core wakeups, and the batch transfer of the buffered data can improve the power efficiency of the sensor data transmission. BNO055 [8], a sensor hub developed by Bosch has a feature to sleep some sensors except the accelerometer if it is detected that there is no movement based on the data from the accelerometer.

This paper proposes a sensor data compression mechanism to consider the characteristics of applications that utilize the sensor based on the degree of change of data input from sensors. This increases the efficiency of the buffer that stores the sensor data. In addition, we proposed a method to operate some sensors in sleep mode to reduce the power consumption of the sensors themselves.
3 Sensor data compression and power management scheme

Conventional sensor data buffering and processing methods store and utilize all the input data collected by sensors. However, if a very small value change due to an error of the sensor itself or if a change in a very small sensor input value is regarded as the same input value, the buffering requirement can be reduced without lowering the accuracy of the motion recognition. This paper proposes a sensor data compression method that considers small change of the sensor input value as the same value. In addition, we proposed a power management scheme that allows sensors other than the accelerometer to operate in the sleep mode when the change of the sensor input values is continuously small.

To perform the proposed compression and power management scheme, several registers are added to the conventional sensor hub as shown in Fig. 1(a). Enabled sensor list and each Sampling rate register are used to set the behavior of the sensors connected to the device. The buffer memory is allocated to each sensor based on the sampling rate of each sensor. The value of Compress threshold is used to determine whether the new input sensor data is stored. Fig. 1(b) shows an example when the Compress threshold is set to 0.5. The value of the new accelerometer input is compared with the previous value of it that is stored in the buffer. If the difference between these two values is smaller than 0.5, only the count value is increased by 1. Each buffer entry in the conventional buffering mechanism has three two-byte fields to store three-axis input values of x, y, and z, respectively. The buffer entry of the proposed scheme has one more two-byte field, i.e. count field, to store a count value in addition to x, y and z-axis field. Max buffering time means the longest buffering time before sending the stored data to the sensor hub core. If the running application needs to output the result every second, Max buffering time should be set equal or less than 1 second. Low-power threshold is a threshold value to change the power mode of the sensors.

In motion-related applications, various sensors are used along with accelerometers to improve recognition accuracy. However, sensors such as gyroscopes consumes much energy. For 6-axis IMU, like the LSM6DS3 [3], consumes 120 µA of current when using only an accelerometer at a sampling rate of 200 Hz. At that same sampling rate, using both the accelerometer and gyroscope together consumes 900 µA of current.

To reduce the power consumption of the gyroscope, this paper proposes a power management scheme based on the characteristics of the target application.

![Proposed sensor hub structure and data compression scheme](image-url)
If \(|\text{ACC\_pre} - \text{ACC\_cur}| > \text{Compress\_threshold}\) //for any one of all axis values
{
  \text{ACC\_cur} \text{ is stored in the buffer},
  \text{Count} = 0 \text{ of the buffer entry.}
  \text{If the sensors other than the acceleration sensor was turned off,}
  \text{Wake all sensors.}
}
else
{
  \text{Count++ of the latest buffer entry}
  \text{If Count > low-power threshold}
    \text{Switch the sensor other than the acceleration sensor to the sleep mode}
}
\text{If the buffer is full or Timer\_value > Max\_buffering\_time}
{
  \text{Wake up main processor}
  \text{All the sensor data in the current buffer is transferred to core memory.}
}

Fig. 2. Pseudo code of the two proposed mechanisms.

The motion detection application that is our primary target application has those characteristics if the value change of the accelerometer input is small, the value changes of other sensors are usually insignificant. In the case of the motion recognition of a wearable device mounted on a wrist or the like, it is very rare that the meaningful change in the value of a gyroscope or other sensors occurs unless there is a meaningful change in the input value of the accelerometer. By using these characteristics, the power consumption can be reduced by switching the sensors other than the accelerometer to the sleep mode when there is only a small change of the accelerometer input more than some specific time period, i.e., Low-power threshold.

The pseudo code for compression and power management scheme is shown in Fig. 2. The sensor data compression mechanism performs compression according to the amount of the change in the accelerometer input. As shown in Fig. 2, ACC\_pre is the previous value of the accelerometer input stored in the buffer memory and ACC\_cur is the current value of the accelerometer input. If the amount of change is greater than the Compress threshold, just the current accelerometer input is stored to the buffer. Otherwise, just increase the count value of the buffer entry for the previous accelerometer input is incremented by 1. The stored sensor data buffer sets are transmitted to the core when the buffer is full or the maximum buffering time is past. The timer is used to calculate the buffering time. If it is larger than Max buffering time, the buffered data are sent to the core. Power management scheme with compression is represented as italic characters in pseudocode. This mechanism is performed by referring to an incrementing count value when the compression is continuously performed. If the count value is greater than or equal the Low-power threshold, the sensors other than the accelerometer are switched to sleep mode, and when the sensor input data is changed more than the compression threshold, the sensors are awakened.

Because the sensor data compression mechanism provides additional buffer space, which increases the bufferable period, number of core wakeups and, the power consumption of the sensor hub can be reduced. The power management scheme with compression reduces the power consumption further by turning off the sensor other than the accelerometer when the movement is insignificant for a long time.
4 Evaluation

4.1 Simulation environment

To verify the effectiveness of the proposed schemes, the analysis is performed using a motion recognition application [9] based on LIBSVM [10]. This classifies six motions, those are: stop, walk, run, jump, lifting dumbbells and jumping jack. In the sampling period of 200 Hz, the motion is recognized every 1 second and the maximum buffering time is set up to 1 second. The capacity of the buffer is assumed to store 20 sets of sensor data. The total sensor data set used for the simulation was 24,000 for both input data from the accelerometer and the gyroscope. The sampling period was set at 200 Hz and was collected for a total of 2 minutes. For the analysis of the power consumption, we use the parameters for the electrical characteristics of the LSM6DS3 [3] IMU from STMicroelectronics. For the LSM6DS3, the electrical characteristics at 208 Hz, a sampling rate close to 200 Hz, are $V_{dd} = 1.8$ V and $Current = 120 \mu$A when using the accelerometer only, and $V_{dd} = 1.8$ V and $Current = 900 \mu$A when using accelerometer+gyroscope.

4.2 Evaluation results of proposed mechanism

To confirm the effectiveness of the proposed compression schemes, we verified the correctness of the motion recognition result with various value of the Compress threshold. Simulation results show that there is a difference in the results of motion recognition applications in thresholds exceeding $(4 \text{ m/s}^2)$ as shown in Fig. 3(a).

We also measured the number of core wakeups and the amount of data transferred to the core, and the proposed compression scheme reduced both the wake-up count and the amount of data significantly as shown in Fig. 3(b).

As a result of combining the two experiments, the number of core wakeups, which have the most direct effect on power dissipation, decreased from 1200 (no compression) to 262 $(4 \text{ m/s}^2)$. At the same $4 \text{ m/s}^2$, the amount of data sent to the sensor hub core to process 24,000 sets of data also decreased by 78%. This confirmed that proposed sensor data compression mechanism can reduce the power consumption and the amount of sensor data transmission about 78% without any recognition accuracy degradation when the Compress threshold is $4 \text{ m/s}^2$.

The power consumption reduction is also analyzed with the proposed power management mechanism. The parameters related to the power consumption are used by referring the LSM6DS3 [3] from STMicroelectronics and $4 \text{ m/s}^2$ compress threshold is used based on Fig. 3(a). The value of Low-power threshold is set to 10.
Evaluation results show that the proposed power management scheme reduces the power consumption of the sensors by 56%. It also reduces the power consumption of the sensor by about 39% more than the power management mechanism to switch sensors other than accelerometers to sleep mode only in the stop motion like [8]. The time duration in the stop motion is assumed as $\frac{1}{6}$ of the total measured time in Fig. 4.

### 5 Conclusions

This paper proposed a sensor data compression mechanism and a power management scheme to reduce the power consumption of a sensor hub that performs the motion recognition.

The proposed compression mechanism compresses sensor data based on the amount of change in the input sensor data. The simulation results confirmed that the proposed compression mechanism can reduce the number of wakeups of the core from 1,200 to 262 compared to the simple buffering method, and reduce the amount of sensor data transmission by about 78%. In addition, IMU power consumption was reduced by 56% by the proposed power management scheme with no recognition accuracy loss. This mechanism adaptively switches other sensors except the accelerometer to sleep mode when there is very small change in the value of accelerometer for long time.

While the target application of this paper is the motion recognition application, it is expected that proposed mechanism can be applied to other applications with appropriate compression threshold and low-power threshold based on the analysis of the characteristics of those applications.

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