



Bachelor's Thesis

Accessing and transferring sensor data on Wearables in real-time

**Zugriff und Übertragung von Sensor Daten auf Wearables in
Echtzeit**

by

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Potsdam, July 2016

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Disclaimer

I certify that the material contained in this dissertation is my own work and does not contain significant portions of unreferenced or unacknowledged material. I also warrant that the above statement applies to the implementation of the project and all associated documentation.

Hiermit versichere ich, dass diese Arbeit selbständig verfasst wurde und dass keine anderen Quellen und Hilfsmittel als die angegebenen benutzt wurden. Diese Aussage trifft auch für alle Implementierungen und Dokumentationen im Rahmen dieses Projektes zu.

Potsdam, June 21, 2016

(Stephan Schultze)

Kurzfassung

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Translating abstract

An academic abstract typically outlines four elements relevant to the completed work:

- The research focus (i.e. statement of the problem(s)/research issue(s) addressed)
- The research methods used (experimental research, case studies, questionnaires, etc.)
- The results/findings of the research
- The main conclusions and recommendations

Abstract

Wearable devices such as smartwatches or activity trackers with embedded sensors are capable of exchanging data with other connected devices. This data will often be transferred to the manufacturer or processed directly on a connected smartphone in order to provide user feedback based on the analyzed data. Almost every wearable device offers third-party developers a way to gain (at least partial) access to the gathered sensor data, allowing custom applications to process them.

In the course of this work, the availability of APIs¹ on different wearables and how likely they can be used to transfer and process sensor data in real-time has been evaluated, as well as the suitability of current devices running proprietary operating systems created by Apple, Google, Jawbone and Microsoft. In addition, an in-depth look at possible implementations for real-time processing of sensor data from devices running Android Wear is included.

¹Application Program Interfaces, provided by the manufacturer

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1. Introduction

When speaking about mobile devices and wearables, it might not be exactly clear which kind of hardware I'm talking about.

Mobile devices are smartphones or tablets in this context. Most of the currently available mobile devices offer capabilities that could only be expected from desktop PCs a few years ago.

Wearables can be described as technology gadgets that you can wear on your body, e.g. around your wrist. Usually they are loaded with sensors and can be connected to an other mobile device via Bluetooth. The most commonly used wearables are smartwatches and fitness trackers, but the technology can also live in clothing or jewellery.

1.1. Motivation

The data produced by sensors on wearables can be valuable for multiple use-cases, for example:

- **Activity feedback:** A big selling point for wearables is the ability to track fitness activities in order to improve the health of the person wearing them. Of course this tracking works by analysing sensor data, e.g. to count the steps or track the heart rate.
- **Event triggers:** Many wearables lack large user interfaces - in order to interact with them, one can use gestures. A smartwatch can turn on its screen if you raise your wrist, but in the background a gesture detection system requires access to the device orientation and acceleration.

While some wearables can work as stand-alone devices, they usually depend on connected mobile devices to some extent. That is because the available space for hardware components is very limited, leading to a lower battery and CPU² power. However, the device sensors on wearables can produce a large amount of data every second. This data may need to be pre-processed, analysed or

²Central processing unit

persisted - all of which requires a lot of processing power and will drain the device battery. Thus, heavy work loads like these should be done on a connected mobile device and presuppose a performant way to transfer data.

1.2. Project Scope

The goal of my Bachelor project “Passwords are Obsolete - Seamless authentication using wearables and mobile devices.” was to authenticate a user by utilizing only data from devices that the user already owns. I opted for training classifiers to analyse how a user performs certain activities and to distinguish between behaviour patterns. These classifiers take raw sensor data or extracted features and perform different machine learning methods.

This unsupervised learning approach required that a wearable can exchange data with a mobile device in a performant yet battery friendly way while keeping the delay in an acceptable range.

2. Related Work

2.1. Project Abacus

- What's different

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2.2. Papers

- Combine abstracts

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3. Devices

I had to build prototypes for research purposes and needed to decide which wearables I intend to work with. Although I wanted to support the widest range of devices that I could, I had to ditch some in order to be able to iterate fast. In the following section, I will list the advantages and disadvantages of different wearables.

3.1. Apple Watch

While the currently available Apple Watches all provide sufficient hardware and enough sensors, the software doesn't allow 3rd party developers to take full advantage of this. With WatchOS 2, Apple restricted apps running on the watch to only get access to sensor data while it's visible to the user. For my project however, I needed a way to access sensor data from a background service, which simply isn't possible with the existing APIs. Apple announced that in WatchOS 3 (which isn't available yet), this restriction will be eliminated.

3.2. UP by Jawbone

- 2h API delay
- Can't provide required data frequency

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3.3. Microsoft Band

- Awesome, but less users than competition
- Limited to SDK functionality

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3.4. Android Wear

Android Wear is a platform for smartwatches that many devices from different manufacturers build upon. Although it's customized to match the conditions of a watch, it's still a full Android OS without any limitations. Because of Android's open nature, it's possible to use everything that the devices offer without any software restrictions.

Unlike the Apple Watch, Android Wear devices are able to connect to devices that don't belong to the same ecosystem, which increases the number of potential users.

4. Implementation

To showcase and benchmark my work, I created an Android App that visualizes sensor data from the device that it runs on and also from connected Android Wear devices. The app is called Sensor Data Logger (1) and can be downloaded for free from the Google Play Store³.



Figure 1: Sensor Data Logger App

Code samples in the following sections are snippets from this project and can be seen in context in the GitHub repository⁴.

³<https://play.google.com/store/apps/details?id=net.steppschuh.sensordatalogger>

⁴<https://github.com/Steppschuh/Sensor-Data-Logger>

4.1. Accessing Data

Android provides the `SensorManager`[1] system service class in order to grant applications access to the device sensors. The supported sensors can be divided into three categories:

- **Environmental sensors** (thermometers, barometers and photometers)
- **Motion sensors** (accelerometers, gyroscopes and gravity sensors)
- **Position sensors** (magnetometers and orientation sensors)

Not all sensors are hardware components, the so called “virtual-” or “synthetic sensors” derive their data from one or more hardware-based sensors. Examples for these virtual sensors would be the linear acceleration sensor, which computes its data based on the accelerometer and the force of gravity.

All sensors can be accessed through the Android sensor framework, which provides classes and interfaces that can be used to figure out which sensors are available on the current device, which capabilities they have and what data they produce.

4.1.1. Checking Availability

While most devices have an accelerometer and a magnetometer, only a few have a thermometer. The availability of sensors can’t be guaranteed, it’s good practice to check this at runtime:

```
1 // get a SensorManager instance
2 SensorManager sensorManager = (SensorManager) getSystemService(Context.SENSOR_SERVICE);
3
4 // get a list of available sensors
5 List<Sensor> deviceSensors = sensorManager.getSensorList(Sensor.TYPE_ALL);
6
7 // check if an accelerometer is available
8 Sensor accelerometer = sensorManager.getDefaultSensor(Sensor.TYPE_ACCELEROMETER);
9 if (accelerometer != null) {
10     // use accelerometer
11 } else {
12     // perform error handling
13 }
```

If a sensor is available, public methods from the `Sensor`[2] class can be used to get detailed information about it. The name, vendor, version, data range and reporting delay are useful properties, especially because one device can have multiple sensors of the same type.

4.1.2. Monitoring data changes

In order to get access to the actual data, a `SensorEventListener`[3] needs to be registered at the `SensorManager` instance. The `SensorEventListener` is an interface which exposes two callback methods:

```
1 // create a new SensorEventListener
2 SensorEventListener listener = new SensorEventListener() {
3     @Override
4     public void onSensorChanged(SensorEvent event) {
5         // sensor reported new data
6     }
7
8     @Override
9     public void onAccuracyChanged(Sensor sensor, int accuracy) {
10        // sensor accuracy changed
11    }
12 };
13
14 // specify a reporting delay for the sensor
15 int delay = SensorManager.SENSOR_DELAY_NORMAL;
16
17 // register the listener for the accelerometer
18 sensorManager.registerListener(listener, accelerometer, delay);
```

The `onSensorChanged` method will be called every time the sensor updates its values. The passed `SensorEvent`[4] holds the sensor, a timestamp, the accuracy and an array of floats containing the actual values.

If the sensor accuracy changes, which often happens when using location sensors, the `onAccuracyChanged` method will be called. It can be useful to care about these accuracies, the location obtained from the Cell-ID or Wi-Fi might be more accurate than the latest GPS coordinates for example. In other cases sensors might need a few seconds to calibrate, like the magnetometer.

When registering a `SensorEventListener`, a delay in microseconds is also passed to the `SensorManager`. It's worth to notice that this value is more like a suggestion, as other applications and the system can alter it. Because the reporting delay can impact the battery life of the device, some manufacturers will lower the reporting interval when the device is idle or the display is turned off.

4.1.3. Monitoring lifecycle changes

Once a `SensorEventListener` is registered, the system will keep the requested sensor active and continue to report data, even if the user left the application. Hence, one should always unregister listeners as soon as possible in order to prevent battery drain:

```
1 public class SensorActivity extends Activity implements SensorEventListener {
2     private SensorManager sensorManager;
3     private Sensor accelerometer;
4
5     @Override
6     public final void onCreate(Bundle savedInstanceState) {
7         super.onCreate(savedInstanceState);
8         setContentView(R.layout.main);
9         sensorManager = (SensorManager) getSystemService(Context.SENSOR_SERVICE);
10        accelerometer = sensorManager.getDefaultSensor(Sensor.TYPE_ACCELEROMETER);
11    }
12
13    @Override
14    public final void onSensorChanged(SensorEvent event) {
15        StringBuilder log = new StringBuilder("Acceleration:");
16        log.append(" X: ").append(String.valueOf(event.values[0]));
17        log.append(" Y: ").append(String.valueOf(event.values[1]));
18        log.append(" Z: ").append(String.valueOf(event.values[2]));
19        System.out.println(log.toString());
20    }
21
22    @Override
23    public final void onAccuracyChanged(Sensor sensor, int accuracy) {
24        // sensor accuracy changed
25    }
26
27    @Override
28    protected void onResume() {
29        super.onResume();
30        sensorManager.registerListener(this, accelerometer, SensorManager.SENSOR_DELAY_NORMAL);
31    }
32
33    @Override
34    protected void onPause() {
35        super.onPause();
36        sensorManager.unregisterListener(this);
37    }
38 }
```

This very basic example activity would print accelerometer data to the console once deployed. Keep in mind that it lacks exception handling, as mentioned in 4.1.1. I presume a basic understanding of how the Android activity[5] lifecycle works.

4.2. Transferring Data

- What to transfer
 - suitable data types
 - serialization
- How to transfer
 - Available APIs and Protocols
 - Pros and cons of different methods

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5. Evaluation

5.1. Benchmarks

- Transferred data per second
- Delay
- Serialization overhead
- Battery impact
- Different devices / API versions

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6. Future Work

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6.1. Open Research Questions

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6.2. Extensions

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7. Conclusion

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A. Appendix

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