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Computer Architecture of Wearable Technology

Author:

Matthew HICKEY

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Executive Summary

The executive summary for this report will be handed in as part of the final draft. It would make no sense to complete the executive summary at this point, as not all the content has been finished yet, and it would make no sense to attempt to summarize an incomplete report.

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1 Introduction

Wearables as defined by Technopedia are technologies that are worn on the body that contain various sensors that can record health and fitness information, or take movement input data in real-time [1]. The market for this technology has expanded rapidly in recent years, with the wearable market being worth $19 billion in 2015, and expected to expand to $57 billion by 2022 [2]. This growth rate can be attributed to the fact that it is a novel technology just getting past the early adoption phase, but this technology is also improving at an impressive pace each year. The 2010s have seen advances in lower-powered processors with a smaller footprint that allow wearable devices to become much more powerful. With improvements in small, powerful processors, it allows wearables to have more functionality, and focus less on designing the wearable around the electronics inside [3]. Clearly, this demonstrates the design requirement for low-power and small components to architects of wearable technology.

While there are many types of wearables on the market in present-day 2019, this report will focus on two types of wearable technology: smartwatches, which record movement data for health and fitness purposes; and virtual/augmented reality (VR/AR) headsets and head-wear, which process movement data in real time for immersive digital experiences.

2 Smartwatches

2.1 Background

The most popular type of wearable in 2019 is the smartwatch [4]. Smartwatches are devices worn on one's wrist, equipped with sensors, and in some cases wireless communication capability for syncing data to a smartphone. They have rich operating systems (OS), on-board processors and memory, and come in a wide range of varieties from basic to high-end, with different specialized models in between [5].

2.2 Typical Specifications

Modern smartwatches typically have similar components to computers, albeit at a much smaller scale. They have an OS, which is most cases is proprietary to the manufacturer (i.e. watchOS for Apple); a single- or dual-core processor ranging from 80MHz to over 1.2GHz depending on the type of watch; up to a gigabyte of memory; battery life ranging between 18 hours to over a week; and depending on the watch - sensors to measure heart rate, fitness statistics, and atmospheric pressure [5].

It is simple to build a system that can accommodate all the required features of a smartwatch using normal computing components, however the challenge with a smartwatch is weight, size, and power consumption, as it needs to fit comfortably on the wrist, and be able to record data for at least an entire day on a single charge. This means all components must be lightweight, and energy efficient. According to ARM, the most necessary optimizations are using small data memories, using slower clock speeds, and choosing a silicon process technology that will offer the lowest possible power consumption, meaning the biggest design trade-off when designing smartwatches is between performance and power consumption [6]. To examine these trade-offs, two popular smartwatches will be analyzed for the architecture decisions that went into their design and manufacturing.

2.3 Analysis of Examples

Two popular examples of smartwatches are the Apple Watch Series 5, and the Garmin Forerunner 235, both shown below in Figure 1. These devices are priced quite differently, carry different levels of functionality, and are therefore targeted towards different market segments. Shown below in Table 1 are prices for the watches listed above [7] [8].

(a) Apple Watch Series 5 [7]

(b) Garmin Forerunner 235 [8]

Figure 1: Smartwatches discussed in this report.

Table 1: Smartwatch Prices

Watch	Price (CAD)
Apple Watch Series 5	529.00
Garmin Foreruner 235	319.99

Clearly, these watches come at different price points, target different segments of the market, and of course come with different architectures for accommodating the necessary features in each model. This section will cover each of the watches shown above in greater detail.

2.3.1 Apple Watch Series 5

2.3.1.1 Background

The Apple Watch Series 5 is the newest iteration of smartwatch from Apple Inc., released in September 2019. Priced at $529, clearly this is considered a higher-end smartwatch, fitting in with Apple's other product lines (iPhone, iPad, and Mac). This watch weighs between 30-40g depending the case, it has all-day battery life, a touch screen (324x394), voice call, GPS, compass, and music streaming capabilities, as well as the ability to run thousands of apps from the Apple App Store made specifically for the Apple Watch [9]. This device is made for Apple users, as it requires an iPhone to make use of all its features. Its operating system is the Apple-designed watchOS.

Much of what makes the Apple Watch quite appealing is the variety of sensor technology that can track much of your health and fitness data. This sensor technology will be discussed, along with other computer architecture components in this section.

2.3.1.2 Hardware and Functionality

An innovation brought on by the Series 5 is the always-on display, a first for Apple Watch. An always-on display is not ideal for a device wanting low-power consumption, especially a high-resolution screen with a high refresh rate like the one on the Apple Watch. However, this new model incorporates a low temperature poly-silicon and oxide (LTPO) display which reduces the refresh rate of the watch's screen from 60Hz to 1Hz, the minimum frequency for the always-on display to accurately display the time [9]. This is a clever way to reduce power consumption by reducing frame rate when the watch is not being used interactively.

The processor and System in Package (SiP) at the core of the Apple Watch Series 5 is Apple's S5 chip, shown below in Figure 2. This is the fifth iteration of their custom-designed smartwatch chip where the entire system is fabricated into a single component with a footprint of about 40mm. This SiP includes 32GB of storage, the memory, as well some the sensors that come with the Series 5, including its GPS component and magnetometer (compass) [9].

Figure 2: Apple S5 Processor [10]

The Series 5 incorporates other sensors whose data is processed. These sensors are an electric heart rate sensor, which constantly monitors heart rate, and can perform an electrocardiogram (ECG/EKG) almost as accurate as a single-lead EKG [11]. Data from this sensor can be monitored and programmed to alert the wearer if there is any abnormal heart activity. The watch also uses its microphone to monitor noise levels, and alerts the user when current noise exposure could pose a risk for long-term hearing damage.

Arguably the most important sensors on a smartwatch with fitness tracking capabilities are the accelerometer, which actually tracks the motion patterns of the watch itself based on acceleration forces [12], and the gyroscope. Data from GPS, accelerometer, gyroscope, heart rate monitor, and your own personal health data (height, weight, age) are used together to give you valuable insights into your workouts. The Series 5 comes with pre-programmed sports like cycling, running, swimming, and yoga, amongst others. In running activities, the watch tracks and can display your calories burnt, your pace, your heart rate, your distance, cadence, and elapsed time [13]. Having this data displayed in real time on your wrist, and available for analysis after the run is something that makes this device so valuable, as it helps people stay motivated and quantitatively monitor their improvements.

2.3.1.3 Apple Watch Summary

After analyzing the price-point, features, and specifications of the Apple Watch Series 5, it is clear this is a high-end wearable device that values performance highly for a wearable device. It has a battery that needs to be recharged each night, and while it carries valuable stats for many different workouts, this app is targeted at individuals who want to exercise to remain healthy, and not so much professional athletes or athletes who need high-performance functionality for hours at a time (ultra-marathoners and Iron-man Triathletes), as the battery would exhaust itself before the workout finishes, as using all sensors (especially GPS) for extended periods depletes battery life rapidly [14]. Therefore, this wearable device's main purpose is to allow for smartphone-like functionality on your wrist.

2.3.2 Garmin Forerunner 235

2.3.2.1 Background

If its name wasn't obvious enough, the Garmin Forerunner 235 is first and foremost a runner's watch. It weighs 42g, and has a slightly larger footprint than the Apple Watch, fitting in a 45mm square. It costs $319.99, which is significantly less expensive than the Apple Watch Series 5. Battery life using it without GPS functionality is 9 days, whereas one charge gives 11 hours of GPS usage. The display (215x180) is not touch screen, navigation is done with buttons on the side. It can connect and sync data to a smartphone, but it can also be used independent of any other device. The sensors in this device include GPS, heart rate monitor, and an accelerometer [8]. It run's Garmin's own proprietary smartwatch OS [15].

What makes the Forerunner appealing is the trade-offs it makes in comparison with the Apple Watch for specializing the device to be a pure running wearable. These specializations and optimizations will be discussed in this section.

2.3.2.2 Hardware and Functionality

There are not many resources that explain in detail the exact architecture of the Forerunner's hardware, however it is safe to assume it uses a low-footprint, low-power processor, along with on-board memory. The exact capacity of the memory is not given, but the watch can store 200 hours of activity data [8].

It is also safe to assume that the processor in the Forerunner is slower and uses less power than the S5 of the Apple Watch, as normal operation of the Forerunner lasts days longer than the Apple Watch.

Like the Apple Watch, the Forerunner comes pre-loaded with activities, but is primarily focused on running and cycling [8]. It takes many of the same running metrics as the Apple Watch, like cadence, pace, heart rate, and distance, as shown in Figure 3. However, the Forerunner can do so for longer periods due to a lower power consumption. An interesting feature built into the Forerunner is the ability to load "courses" onto the watch and have the GPS guide you through turn-by-turn [16]. The Apple Watch does not offer this without downloading a third-party application, which likely uses more power than built-in functionality.

Figure 3: Mid-run display on Forerunner displaying distance, time, and current pace.

2.3.2.3 Garmin Forerunner 235 Summary

It is clear that the Garmin Forerunner does not attempt to be the "smartphone on your wrist" that the Apple Watch offers. The Forerunner is an energy efficient wearable that is specialized for tracking running activities. It is not meant for people who wants lots of functionality in their smartwatch, but for people looking for a reliable, efficient watch they can use for their fitness tracking and not have to charge every single day. Therefore, the Garmin Forerunner 235 is an example of how power consumption is prioritized over performance in the power-performance trade-off of wearables, as functionality is optimized to only have the necessities.

2.4 Smartwatch Summary

Comparing as contrasting the Apple Watch Series 5 and Garmin Forerunner 235 is an insightful case study for different varieties of smartwatches. It illustrates different trade-offs between performance and power consumption, and shows how regardless of the type of wearable, the footprint of the hardware, and power consumption are the two most important design criteria and constraints.

3 Virtual Reality

3.1 Background

Virtual Reality (VR) technology is an area of wearables that have been on the rise as computer hardware capabilities improve. The Virtual Reality Society defines VR as a 3D environment generated by a computer that a person can interact with, and be immersed in such a way that the person can manipulate and interact with the environment much like they would in *actual* reality [17]. High-quality technology and intelligent architectures are required to realize VR due to the compute-intensive task of processing many inputs and rendering a virtual world/environment in real time, and depending on the level of detail (LoD), is an intensive task on its own [18]. Therefore, it is necessary to make intelligent architecture design decisions to ensure the VR wearable operates as intended, and with the correct performance specifications.

The most common type of VR wearable is the VR headset, and example is shown below in Figure 4. As illustrated, the headset is worn on the head (making it a wearable), and its screen takes up the user's entire field of view - thereby immersing them in a virtual environment. Some headsets include audio capabilities and movement sensors, but this will be discussed later in this section.

Figure 4: Example of archetypical VR headset [19]

3.2 Typical Use Cases

Due to the immersive and potentially high-fidelity rendering that VR can accomplish, there are several key applications where this technology can be applied. For example, VR has the potential for entertainment, business, and medical applications.

3.2.1 Entertainment

For entertainment applications, VR has the potential to revolutionize video games. VR offers the ultimate level of immersion, and allows players to feel as if they are a part of the world in which they are playing, as shown below in Figure 5. Different VR technologies offer additional peripherals, which can include treadmill-like surfaces to track players' movements in-game without a controller, and controllers shaped like gloves that offer haptic feedback when players interact with objects in-game, thereby taking away elements that limit the immersion of video games [20].

Figure 5: Playing a video game in VR [21]

3.2.2 Business

For business applications, VR can be used for modelling buildings before they break ground, but also for completing expensive and dangerous training exercises at a lower cost, and with zero risk - like ExxonMobil has started doing recently. Exxon's VR simulator is quite advaned, letting users manipulate the virtual world by tracking their head, arm, and leg movements to allow them to complete virtual practice work on a model of one of Exxon's real assets [22]. An example of Exxon's setup is shown in Figure 6. This allows extensive training to be completed with zero consequence of failure and without having the need to actually send trainees to the platform.

Figure 6: An ExxonMobil employee trains using VR [22]

3.2.3 Medical

For medical applications, VR can be used as both a training tool (shown in Figure 7), and can allow the opportunity for telepresence surgery, where a surgeon can operate on a patient through virtual reality from a remote site, while complex machines follow the surgeon's actions with acute precision [23]. This will allow for doctors to receive life-like training without having patients going under the knife, and will allow patients requiring surgery in remote locations to have specialized surgery without the presence of a specialized surgeon.

Figure 7: A surgeon trains using VR [24]

3.3 Analysis of Examples

Two popular examples of virtual reality headsets are the Oculus Quest and the Oculus Rift S, both shown below in Figure 8. Much like the two smartwatches discussed earlier in this report, these two headsets have different capabilities, which will be discussed later. The pries for these two headsets are listed below in Table 2 [25] [26].

(a) Oculus Quest VR Headset [27]

(b) Oculus Rift S VR Headset [28]

Figure 8: VR headsets discussed in this report.

Table 2: Smartwatch Prices

Headset	Price (CAD)
Oculus Quest	549.00
Oculus Rift S	549.00

Even though these two headsets come at the same price, they are targeted at different market segments, and their architecture reflects that.

3.3.1 Oculus Quest

foobar foobar

3.3.2 Oculus Rift S

foobar foobar

4 Conclusion

This section will be completed when VR/AR section is complete and there are appropriate conclusions to draw.

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