Enhancing Smartwatch Efficiency with E-Paper Display and Power Harvesting Technologies

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Abstract*— The rapid proliferation of smartwatches has revolutionised personal technology, yet persistent issues of battery life, sustainability and outdoor visibility remain. This project addresses these challenges by integrating e-paper displays and power harvesting technologies into smartwatch design. E-paper displays offer superior visibility in sunlight and significantly lower power consumption compared to traditional LCD screens. The project also explores power harvesting techniques, such as harnessing ambient light and kinetic energy, to extend battery life for several months. Emphasising sustainability, user empowerment, and data privacy, the design incorporates open-source principles, allowing users to modify and upgrade their devices. Additionally, a lightweight operating system and optimised power management strategies enhance efficiency. Through iterative prototyping and rigorous testing, this project aims to develop a durable, energy-efficient smartwatch that meets modern user expectations while minimising environmental impact. This innovative approach seeks to set new standards in smartwatch technology, emphasising long-term usability and sustainability.

I. Introduction

Smartwatches have become integral companions in our daily lives, offering convenience and functionality at our fingertips. However, traditional smartwatch displays often face challenges in outdoor visibility and battery life (Figure 1). In response to these challenges, this project aims to enhance smartwatch efficiency by integrating an e-paper display and leveraging power harvesting technologies.

Figure 1 - Comparison between LCD and E-Paper in a sunny environment (iPhone on full brightness).

Previous work in smartwatch design has laid a foundation for innovation, but there remains a gap in addressing visibility and battery life concerns simultaneously. Current e-paper displays offer superior visibility in outdoor environments, while power harvesting technologies present opportunities for prolonged battery life through ambient energy sources. By building upon existing research and technologies, this project seeks to bridge this gap and push the boundaries of smartwatch design.

This work builds upon an open-source E-paper smartwatch called Watchy [1]. This open-source watch currently is intended for enthusiasts and not for end users, and does not have a touch screen, power harvesting technologies, advanced connectivity, and a water-proof enclosure. As a result, this project is using Watchy as a first brick to get started.

Through the integration of an e-paper display with touch functionality and backlight, along with careful power consumption analysis and simulation, this project aims to create a power consumption model tailored to optimise efficiency. Additionally, considerations for redesigning the enclosure and PCB board to accommodate smaller components and integrate power harvesting capabilities will be explored. This holistic approach will culminate in the development of prototypes that not only maximise efficiency but also pave the way for future innovations in smartwatch technology.

II. Related Work

In the field of academic research, studies have explored the potential of e-paper displays in enhancing visibility and energy efficiency in electronic devices, with the overarching goal of achieving battery life expectations similar to traditional watches. Research has shown that e-paper displays offer significant advantages over traditional LCD screens, particularly in outdoor environments, due to their reflective properties and low power consumption [2]

Additionally, advancements in touch-enabled e-paper technology have expanded the capabilities of e-paper displays, allowing for interactive user experiences similar to conventional touchscreens [3].

On the commercial front, several smartwatch manufacturers have begun integrating e-paper displays into their products to address visibility and battery life concerns, with the objective of meeting consumers' expectations for prolonged battery life. For example, the Pebble smartwatch line gained popularity for its use of e-paper displays, offering users an always-on display with 7 to 10 of battery life [4]. Additionally, emerging brands like Amazfit have introduced smartwatches with low power displays, emphasising extended battery life and outdoor visibility as key selling points [5].

III. First prototype

The current prototype is focusing on optimising the existing open-source firmware to extend battery life. At current stage, battery life could hold up to 15 days.

Figure 2 - Smart watch during daily usage

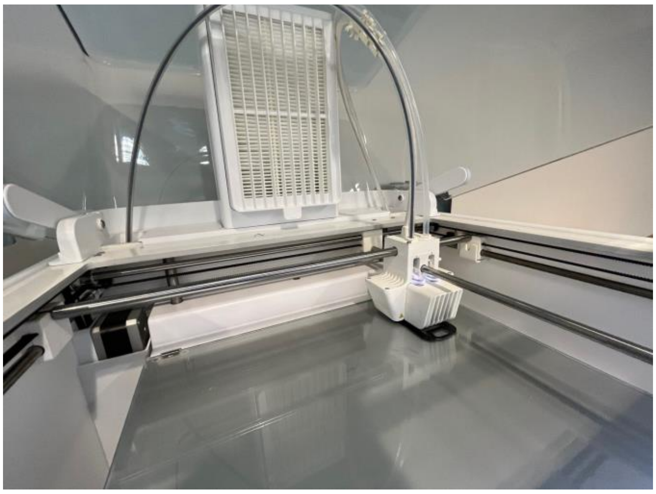

Figure 3 - 3D printing was used to make the enclosure smaller.

Figure 4 - 3D printed enclosure

Figure 5 - Current status of the smart watch

Figure 6 - A look inside the watch

IV. Imagined or existing prototype sketches/drawings/photos

Several steps are planned for the next prototypes:

- Display Upgrade: Prototyping begins concurrently with the display upgrade phase, where the smartwatch display is upgraded to a touch-enabled e-paper display with backlight functionality. This enhancement aims to improve visibility in outdoor environments while maintaining energy efficiency.

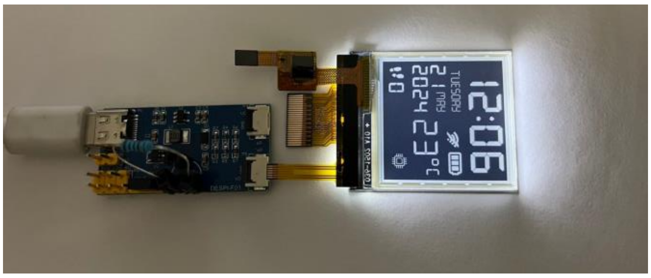

Figure 7 - The new touch E-Paper from Good Display during development

- Power Consumption Analysis and Simulation: Alongside the display upgrade, the project will focus on analysing and simulating power consumption to develop a comprehensive power consumption model. This model will enable accurate estimation and optimisation of energy usage to achieve maximum efficiency.

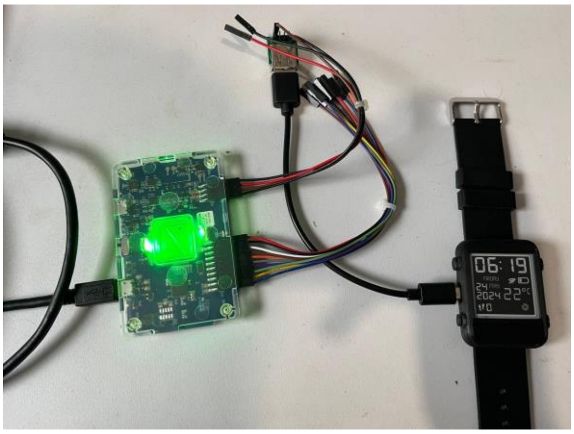

Figure 8 - Using Nordic Power Profiler to study power consumption

- Central Unit Consideration: Based on the findings from the power consumption analysis, considerations will be made regarding the central processing unit (CPU) of the smartwatch. The current ESP32 CPU may be evaluated for its energy efficiency, with the possibility of switching to alternative options such as the NRF series from Nordic Semiconductors.
- Enclosure Redesign: Simultaneously, efforts will be directed towards redesigning the enclosure and PCB board to accommodate smaller components and optimise the internal layout for enhanced efficiency. The goal is to reduce the overall size of the smartwatch while maintaining functionality and durability. Transitioning from 3D printing to plastic injection for enclosure production will be considered to facilitate mass production and scalability.
- Integration of Power Harvesting Technologies: Another key aspect of the project involves integrating power harvesting technologies into the smartwatch design. This includes harnessing ambient light, body temperature, and kinetic movement to supplement battery power and extend battery life.
- Lightweight Operating System Development: In addition to hardware optimisations, the project will involve the development of a lightweight operating system tailored for efficient power consumption. This operating system will prioritise energy efficiency while maintaining essential smartwatch functionalities.

Prototyping occurs in parallel with each stage of the project, starting from the initial display upgrade and continuing through subsequent phases. Separate prototypes will be developed to test and refine each component and functionality of the smartwatch. This iterative process will involve optimising the form factor and ensuring seamless integration of all features.

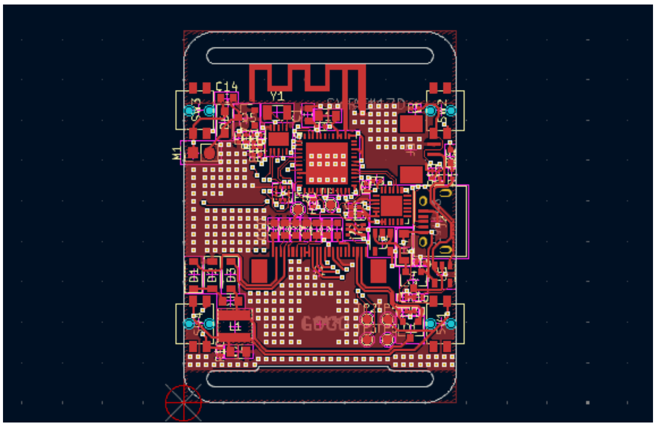

Figure 9 - PCB development on KiCad

- Low-Power Connectivity Features: With Bluetooth and Wi-Fi already integrated, the focus will be on optimizing these connectivity features for low power consumption. This includes implementing energy-efficient protocols and algorithms to minimize power usage during data transmission and reception. Furthermore, the addition of compression algorithms and AI features will enable the smartwatch to anticipate transmission power requirements based on user behaviour, further enhancing power efficiency without compromising connectivity.
- User Interface Refinement: User interface (UI) and user experience (UX) refinement will continue to be a focal point of the next prototype iteration. This includes redeveloping the watch system to incorporate a real-time operating system (RTOS), enabling seamless multitasking and efficient resource management. Additionally, the smartwatch will gain the capability of installing applications, expanding its functionality and customization options. All user interactions will be optimized for the e-paper screen, ensuring smooth performance and intuitive navigation.

- Durability and Reliability Testing: As with previous iterations, the next prototype will undergo rigorous durability and reliability testing to ensure robustness and performance under real-world conditions. This testing will encompass various environmental conditions and usage scenarios to validate the durability and reliability of the smartwatch design.

V. Responsible Innovation

In the development of my e-paper smartwatch, responsible innovation is prioritised to ensure ethical, sustainable, and user-centric design. My approach encompasses various dimensions to address the needs and values of users, society, and the environment.

- Prioritizing longevity and resource efficiency, aiming to minimize electronic waste and reduce carbon footprint throughout the product lifecycle.

- User Empowerment: I empower users by maintaining an open-source approach to both hardware and software. This allows users to modify, upgrade, and customize their smartwatches according to their preferences, extending the lifespan of the device and promoting a circular economy model.

- Data Ownership and Privacy: I prioritize user data privacy and ownership, providing users with the option to connect their smartwatches to their private servers. This decentralized model gives users full control over their data, enabling them to make informed decisions about its storage, processing, and sharing.

- Accessibility and Inclusivity: My smartwatch design considers the diverse needs of users, including those with disabilities or special requirements. I strive to create a product that is accessible, inclusive, and user-friendly for all individuals.

- Security: Security measures are paramount in safeguarding user data and protecting against potential cybersecurity threats. I employ robust security protocols to ensure the integrity and confidentiality of user information.

- Continuous Improvement and Collaboration: I am committed to continuous improvement and collaboration with industry partners, research institutions, and community organizations. Feedback from users and stakeholders is integral to my iterative design process, driving innovation and addressing societal challenges.

VI. Author Bio(s) / Experiences

I have been working in embedded development design for some time and gained experience in IoT technology during my recent master at UCL. Some projects as example:
- A simple device that lets your plant talk with you using emojis: https://github.com/syk-yaman/plantemoji

- A solar-powered LoRa mesh network tested in the Olympic Park, London to sense weather parameters: https://github.com/syk-yaman/lora-mesh

- A smart tool for home & office to control lighting autonomously: https://github.com/syk-yaman/smart-led

And I published a paper about designing a real self-driving car from scratch previously, available on this link:
- https://doi.org/10.1080/23311916.2018.1485458

Currently in my role as a research assistant, I have developed more passion towards IoT, self-powered and low-powered technologies.

VII. Acknowledgements

The development of this project is built upon the open-source code and hardware provided by the Watchy project. I extend my gratitude to the creators and contributors of Watchy for their valuable contributions to the field of wearable technology.

VIII. Refernces

[1] https://watchy.sqfmi.com/

[2] Sánchez-de-Rivera, Diego, et al. "Towards a wireless and low-power infrastructure for representing information based on e-paper displays." *Sustainability* 9.1 (2017): 76.

[3] https://good-display.com

[4] https://www.kickstarter.com/projects/getpebble/pebble-e-paper-watch-for-iphone-and-android

[5] https://uk.amazfit.com/