Sun Watch 3.0

Eli Backer

FROM APPLICATIONS TO GRADUATE SCHOOL:

The Sun Watch has never really worked. Originally intended to show the position of the sun in the sky along a series of lights, it has only ever managed to do that one day at a time, and then never far from a computer needed to reprogram it. Job fairs, conferences, and portfolio day it has sat, proudly on my wrist, barely getting by.
Executive Summary

The team of one working on the Sun Watch is Computer Engineering student Eli Backer, advised and motivated by professor Lynne Slivovsky.

The Sun Watch has been a project for over a year now and was featured in Eli’s portfolio when applying to graduate schools. As can be understood from the sample of text presented on the cover of this report, the Sun Watch never functioned as intended or to a degree where it could be worn every day as a typical wristwatch.

To address these problems, a new enclosure, circuit board, and programming interface were designed. The watch case is now made of two pieces of aluminum, one on the back which contacts the battery, and one on the front which protects the delicate circuit board in the middle. The circuit board in the middle has been slimmed down from 1.6mm to 0.6mm so as to lower the profile of the device. To aid in programming, a more capable programmer was purchased and a programming fixture was developed. Solder stencils were also produced so that panels of 8 watches may be manufactured at a time.

After several weeks of debugging, the watch may be programmed. Given a few more weeks of work, it is anticipated that the Sun Watch will not only be manufacturable on a medium scale (5-50 units), but also usable and maintainable by the people to whom it is given.
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Part I

Final Design Report
Chapter 1

Introduction

1.1 Problem Definition

While a watch that gives the position of the sun may not be useful or practical, constructing such a device should not be impossible. Having developed several prototypes of this device before with varying modes of failure, this third version of the Sun Watch aims to provide a functional platform on which to develop such a device. This means the solution should be mechanically sound, providing a reliable battery contact, and sturdy enough to handle both wrist-strap and battery replacement. User input through the two side switches should be easy. The device should be easily manufactured in larger numbers and easily programmed. Finally, a software toolchain should be in place for quick iteration on the firmware of the device.

1.2 Customer Background

In considering the consumer of the this project, the team looked at two use-cases: the developer and the user. Oddly enough (and perhaps in keeping with a trend of this project) they can be represented by the same person: Eli Backer. Eli is proficient in C programming and Linux use, is willing to put up with failures, and has proven happy to test iterations of the project. Eli also expects the watch to “just work” once development finishes, and to have a product that may be given to friends and family with no programming experience and little instruction. While not as frequent, a jeweler may be considered a third customer as they may be the one to replace the battery when it runs out.

1.3 Specification Development

In the first version of the Sun Watch, programming was impossible, as a chip was selected that could not be programmed by Spy-bi-Wire, a two-wire version of the JTAG protocol. In the second iteration, programming was possible, but spotty and with a lot of cargo-cult-esque rituals which likely had no effect on the outcome. Thus, the primary goal of v3.0 was to have an easy to use and fully capable programmer. The other goals of this version were cosmetic– to reduce the thickness of the device, to make it appear more sleek, user friendly, and polished. These goals all came from the hope that this would be the final iteration of the device, shipped to a few friends and family.

While production is the aim of v3.0, there are still some unanswered questions that are low priority, chief of which is the battery life. While parts have been selected that don’t needlessly waste power, there is no data yet to suggest what the battery life will be like, and this is not a
major concern of the client. When the device is running as intended, battery life tests will be done and a larger battery may be needed. While the device is a watch, it makes not attempts to be waterproof. Any dust or water resistance in the final design will be considered a surprising bonus.

A complete list of our design requirements can be found in Table 1.1. The table is ranked from most significant to least significant requirements and the right column allows for side-by-side comparison of the achieved technical specification in the final design and the original requirements from the start of the project.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Programmability</td>
<td>Spy-bi-Wire</td>
</tr>
<tr>
<td>Dimensions</td>
<td>35mm x 25mm x 7mm</td>
</tr>
<tr>
<td>Ingress Protection</td>
<td>IP20</td>
</tr>
<tr>
<td>Runtime</td>
<td>30 days</td>
</tr>
</tbody>
</table>

**Table 1.1**: Design Requirements
Chapter 2

Background

2.1 Applicable Technologies

The aims of this project are not too out of the ordinary, so the technology required is not very groundbreaking.

Low-Power Microcontrollers

These days any major microcontroller manufacturer is producing low power MCUs. While one may be better than the other at any instant, the gains of one brand over another is not worth the trouble of learning a new workflow– so long as it goes to sleep and draws a few $\mu$A.

Pogo Pins

Frequently used in bed-of-nails testing, pogo pins are, as the name describes, pins that can collapse into themselves a little to make contact with a board. These are particularly well suited to programming side of this project as a watch could be pressed onto the programming board, contacting the pogo pins and receiving information as needed.

2.2 Existing Works

As this project is not really marketable or commercially viable, no one else has built something much like it before.

Sun Light

Sun Light is a light installation by Eli Backer that gradually turns on at sunrise and off at sunset. Controlled by a computer running a python script it may be seen as a precursor to the Sun Watch.

Sundial Watch: The Original Smart Watch

This series of 3d printed pieces was done by Cal Poly Lecturer and Architect Gabriel Kaprielian as a response to the rapid proliferation of smart watches (see fig. 2.1). His work might be mistaken as inspiration for the Sun Watch, but in reality both works were conceived independently around the same time.
Figure 2.1: Prof. Kaprielian’s Sundial Watches
2.3 Benchmark Selection

This is not really an engineering project, with engineering benchmarks. It doesn’t make sense to say that the Sun Watch will be a success if it outperforms product x or y—how would such a test even be performed? Unfortunately, this means the project may never be done, but with life’s pressures, that seems an unlikely scenario.

2.4 Intended Benefits

The device benefits the user by gently reminding them that time need not be the master of their life, in the most/least precise way possible.
Chapter 3

Design Development

3.1 Preliminary Conceptual Design

From the beginning of the project, the device has been 25x35mm with seven side-view LEDs facing perpendicular to the user’s wrist. These decisions were somewhat arbitrary— the size determined by its relationship to standard watch bands, the viewing angle to keep the information private to the user.

Microcontroller

A TI MSP430 was chosen for its low power operation and Spy-bi-Wire interface, which meant only four wires were needed for programming. Unfortunately in v1.0 an IC was selected that did not have a Spy-bi-Wire so 1.0 died a swift death. Version 2.0 had a correctly selected chip, but was somewhat unreliable to program, as a MSP Launchpad (used for programming a specific line of DIP MCUs) was jury rigged to work.

Battery Holders

For all versions, a 16mm diameter coin cell has been used. In v1.0 the cell was sandwiched in between two circuit boards, which proved unreliable, almost never making correct contact. Version 2.0 used a battery clip, but this too had problems, coming desoldered after a few hours use.

3.2 Preliminary Analysis and Decision Making

In exploring the successes and failures of the first two designs it became clear that the form of the Sun Watch was good, but that the circuitry could use a closer, more reliable look. Based on the results of v2.0, the correct programmer for the MCU was found and a programming board was proposed.

In the time between v2.0 and v3.0, the client’s design sensibilities had shifted away from the industrial look of early versions. This not only lead to the need for a case redesign, but also the possibility of a better-made battery system. A sandwich system like v1.0 was proposed, but with two key changes:

1. The top of the sandwich would be machined aluminum instead of stacked circuit boards, to allow for more precise control of depth, and
2. A small leaf contact was added to the back of the circuit board to put pressure on the battery and maintain better contact.
Chapter 4

Final Design - v3.0 &
The Pogo-grammer

Design Brief

The watch will sit on the wrist, activated by switches on the right side and indicating the sun position on its forward edge. The watch is a stack of aluminum bottom, battery, circuit board, SMD components, and aluminum top; secured from the bottom by four bolts, blind-tapped into the top.

A dedicated programming board ("The Pogo-grammer," fig. 4.2) connects to a computer via a TI programmer. This board has four pogo pins which contact the watch circuit board at programming pads. The watch can either be pressed against the board for quick programming or attached for prototyping.

Figure 4.1: Side view of v3.0
Figure 4.2: Pogo-grammer
4.1 Design Details

Mechanical Considerations

The bottom plate is 2.0mm thick to accommodate the 1.6mm high battery and 1.4mm tall screw-heads. The circuit board is 0.6mm thick, which is as thin as rigid PCBs are typically made—any thinner would be a flex-board. Because the board is so thin, the switches on the side need to have cut-outs on the bottom plate to fit properly. The highest point on the populated circuit board is the microcontroller, at 1.0mm. The top plate rests on this and is 2.5mm thick, to give the bolts 1.67mm to thread into (2x the diameter of the screw, the minimum needed). The strap is fed through slots in the bottom plate and secured by two 1.5x1.0mm strips (see fig. 5.2).

The pogo-grammer aligns itself with the watch by alignment bolts, placed in the same location as the bolts that hold the watch together. These may also be used to attach the target watch to the pogo-grammer for rapid debugging.

Electrical Considerations

The most important part of the device (aside from the microcontroller) is the crystal oscillator which will keep accurate time. Thus it is placed as close to the microcontroller as possible, with special care to having a ground plane beneath it and short leads of equal length. Beyond this, most of the design is standard—a pull up resistor on the reset pin, capacitors on the power line, and a current-limiting resistor on the LEDs. The switches are pulled up internally.

Device Operation

The watch is powered by the battery and sun position is displayed when one of the side buttons is pressed. Holding these buttons allows for setting the time and location of the device. Programming the watch is a matter of holding the device to the pogo-grammer and running programming software, such as Code Composer Studio on Windows, or Ez-Flash on Linux.

4.2 Supporting Analysis

Initial Calculations

I am not a mechanical engineer and can make no claims on the integrity of my mechanical assumptions in this project.

The circuit for the watch is simple, with the most crucial component being the crystal oscillator. The oscillator has been laid out on the circuit board as recommended by TI. The rest of the circuit is simple, and determined by rules of thumb. The pogo-grammer has been laid out according to TI’s specification for Spy-bi-Wire connections.

Part Selection

Electrical Components

The primary concern in selecting electrical components was their height; surface area is relatively plentiful on the board. The microcontroller has always been the zenith of components, serving as a natural spacer for all other components to fall under. Thus, with a microcontroller of reasonable height (1mm) all other components needed to be shorter. This was a simple task, though it lead
to the overzealous selection of some 0402 components which are just minuscule and will likely be replaced in v3.1.

**Manufacturing Services**

Fabricating circuit boards and complex, precision-tooled pieces of aluminum are not skills of mine, nor capabilities of the University. Thus I turned to three services I have used before, out of familiarity and confidence in their work for these two tasks. The circuit boards were made by DirtyPCB, an aggregator of Chinese board houses. They can make a board in one week, with options for shipping times ranging from ten days to two months. Front Panel Express is a Seattle-based company that manufactures two-sided aluminum panels. Their turn time is two weeks, including shipping. OSHStencils makes cheap mylar solder stencils that are good for approx. ten boards. These can be manufactured and received in one week or less.

**Mechanical Components**

Given the limitations of Front Panel Express’s blind-tap machines, a M1.6 or larger bolt had to be selected. The Philips head was selected for its ubiquity and low profile. Stainless steel, though more expensive was selected due to it’s resistance to corrosive sweat.

### 4.3 Cost Breakdown

**Cost Estimate**

The projected R&D budget for the project was $500, including the overhead of spare parts, a new programmer, and between 80-96 copies of a PCB of which one may be used.

Given the programmer and other start-up costs, a device should cost no more than $100 to make, with most of that money going to the aluminum enclosure. Table 4.1 shows a simple breakdown of the initial budget. For a full Bill of Materials, please see table A.1 in Appendix A.

<table>
<thead>
<tr>
<th>Category</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Programmer</td>
<td>$115</td>
</tr>
<tr>
<td>Circuit Boards</td>
<td>$50</td>
</tr>
<tr>
<td>Enclosure</td>
<td>$75</td>
</tr>
<tr>
<td>Electrical Parts</td>
<td>$20</td>
</tr>
<tr>
<td>Mechanical Parts</td>
<td>$20</td>
</tr>
<tr>
<td></td>
<td><strong>$280</strong></td>
</tr>
</tbody>
</table>

**Table 4.1:** Simplified Cost Breakdown
Chapter 5

Manufacturing and Design Verification

5.1 Manufacturing Processes

If all suppliers manufacture their parts to the correct tolerance, assembling a Sun Watch is straightforward.

1. The solder stencil is applied and aligned visually through a stereo microscope
2. Solder paste is applied and the stencil is removed
3. Components are placed using a steady hand and microscope
4. Boards are reflowed (see fig. 5.1 for completed panel)
5. Boards are depanelized and deburred with sandpaper
6. The battery leaf spring is hand-soldered into place
7. The board is programmed with a pogo-grammer and tested

The board can also be assembled using a soldering iron and liberal application of flux, though this can yield slightly less elegant, though functional results.
As this is v3.0, there are previous versions and parts on hand. Where early versions of a design might run into unforeseen problems during assembly, Sun Watch 3.0 had no such issues, which can be attributed to careful reading and cautious application of the various datasheets.

5.2 Test Descriptions

With a completed test version of the Sun Watch, testing may begin, foremost of which is the programmability of the device. Once this baseline test is completed, tests concerned with the functionality of the device can begin, such as battery life and durability. For detailed information, please refer to 5.1

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Requirement</th>
<th>Compliance</th>
<th>Verification Plan</th>
<th>Achievement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Programmability</td>
<td>Spy-by-Wire</td>
<td>I</td>
<td>Check all functions of device, programmer connection</td>
<td>Yes</td>
</tr>
<tr>
<td>Runtime</td>
<td>1 month</td>
<td>T</td>
<td>Wear and subject to typical use</td>
<td>Unknown</td>
</tr>
<tr>
<td>Ingress</td>
<td>IP20</td>
<td>T</td>
<td>IP30</td>
<td></td>
</tr>
<tr>
<td>Durability</td>
<td>1 year</td>
<td>I</td>
<td>Considering damage from battery test, extrapolate potential lifetime</td>
<td>Unknown</td>
</tr>
</tbody>
</table>

Table 5.1: Specification Verification Checklist

5.3 Maintenance and Repair Considerations

The main source of repair will likely be the battery. While the case is assembled with Philips-head screws (see fig. 5.2), the 1616 battery used is not as common. However, they are cheap, especially in bulk and can easily ordered from Digikey. It is also hoped that they will be a common item in a jeweler’s kit.

All parts are user replaceable, presuming that a new mainboard would come pre-programmed. This should not be a very hard project, certainly less challenging than upgrading the RAM in an old computer. While none of the parts are outstandingly standard, they are not impossible to source, especially if using the bill of materials.
Figure 5.2: Watch back

Figure 5.3: v3.0 in use
Chapter 6

Management Plan

6.1 Team Members

The Sun Watch Team has delegated responsibilities among group member throughout the project. These roles were representative of the particular skills and expertise of each member. A short profile for each member’s role is listed below:

Eli

As the lead Electrical, Mechanical, and Software Engineer, Eli provided advice on all circuit design, mechanical design, and manufacture. In addition to those technical roles, Eli also wrote this entire report.

Lynne

As project advisor, the Sun Watch Team looked to Lynne for guidance on the technical completion of the product, design critique, motivation, and discussion of fine cheeses.
Chapter 7

Conclusion

7.1 Next Steps

In the past weeks, a fully programmable device has been manufactured, with plans to assemble eight more before Eli graduates and access to the IME lab and its reflow over is lost. Now that the hardware is functioning as expected, programming can begin, first exploring the look-up tables needed to make the device function as intended, then developing a user interface, and finally testing, both battery life and usability.

7.2 Credits

Eli would like to thank: Professor Lynne Slivovsky for all her advice, guidance, and patience throughout the project thus far; Lecturer Jeff Gerfen for teaching a microcontrollers class not based around an Arduino; Jane-Leslie Newberry and Tom Backer for their boundless encouragement, and support; and Elaine Fisher for volunteering as a hand model.
Part II

Appendices
Appendix A

Detailed Bill of Materials

Table A.1 contains a detailed bill of materials with all the components necessary to construct a functioning Sun Watch. Table A.2 provides the same information about the Pogo-grammer.

<table>
<thead>
<tr>
<th>Count</th>
<th>RefDes</th>
<th>Value</th>
<th>Description</th>
<th>Size</th>
<th>MFR</th>
<th>Digikey Part No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>C1</td>
<td>0.1µF</td>
<td>Smoothing capacitor</td>
<td>0402</td>
<td>Samsung</td>
<td>1276-1507-1-ND</td>
</tr>
<tr>
<td>2</td>
<td>BATT</td>
<td>3V</td>
<td>Main battery</td>
<td>16x1.6mm</td>
<td>Panasonic</td>
<td>P034-ND</td>
</tr>
<tr>
<td>1</td>
<td>BATT1</td>
<td>Neg. Cont.</td>
<td>Battery leaf contact</td>
<td>10x4mm</td>
<td>Keystone Elect.</td>
<td>36-112CT-ND</td>
</tr>
<tr>
<td>2</td>
<td>S1, S2</td>
<td>–</td>
<td>Micro tact switches</td>
<td>2.8x2.3mm</td>
<td>Panasonic</td>
<td>P16849CT-ND</td>
</tr>
<tr>
<td>1</td>
<td>U1</td>
<td>MSP430G2453</td>
<td>Low-power MCU</td>
<td>20-TSSOP</td>
<td>TI</td>
<td>296-41339-1-ND</td>
</tr>
<tr>
<td>1</td>
<td>X1</td>
<td>32.7680kHz</td>
<td>Timeclock oscillator</td>
<td>2-SMD</td>
<td>Abracon</td>
<td>535-12058-1-ND</td>
</tr>
<tr>
<td>7</td>
<td>LED1..LED7</td>
<td>Cool White</td>
<td>Side-view LED ind.</td>
<td>0602</td>
<td>QT Brighttek</td>
<td>1516-1080-1-ND</td>
</tr>
<tr>
<td>1</td>
<td>R1</td>
<td>150Ω</td>
<td>Current limiting</td>
<td>0603</td>
<td>Vishay</td>
<td>MCT0603-150-CFCT-ND</td>
</tr>
<tr>
<td>1</td>
<td>R2</td>
<td>47kΩ</td>
<td>Reset pull-up</td>
<td>0603</td>
<td>Panasonic</td>
<td>P47KGCT-ND</td>
</tr>
</tbody>
</table>

*Table A.1: Sun Watch BOM*
<table>
<thead>
<tr>
<th>Count</th>
<th>RefDes</th>
<th>Value</th>
<th>Description</th>
<th>Size</th>
<th>MFR</th>
<th>Digikey Part No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>JP1</td>
<td>3-Pos</td>
<td>Header</td>
<td>0.300in</td>
<td>Molex</td>
<td>WM2723-ND</td>
</tr>
<tr>
<td>1</td>
<td>JP1.2</td>
<td>–</td>
<td>Sel. Shunt</td>
<td>0.200in</td>
<td>Amphenol</td>
<td>609-2217-ND</td>
</tr>
<tr>
<td>1</td>
<td>R1</td>
<td>47 kΩ</td>
<td>–</td>
<td>0603</td>
<td>Panasonic</td>
<td>P47KGCT-ND</td>
</tr>
<tr>
<td>1</td>
<td>R2</td>
<td>330 Ω</td>
<td>–</td>
<td>0603</td>
<td>Panasonic</td>
<td>P330GCT-ND</td>
</tr>
<tr>
<td>1</td>
<td>J1</td>
<td>7x2 header</td>
<td>Prog. header</td>
<td>0.700x0.200in</td>
<td>3M</td>
<td>MHB14K-ND</td>
</tr>
<tr>
<td>1</td>
<td>C1</td>
<td>2.2 nF</td>
<td>–</td>
<td>0603</td>
<td>Samsung</td>
<td>1276-1992-1-ND</td>
</tr>
<tr>
<td>1</td>
<td>C2</td>
<td>10 µF</td>
<td>–</td>
<td>0603</td>
<td>Samsung</td>
<td>1276-1119-1-ND</td>
</tr>
<tr>
<td>1</td>
<td>C3</td>
<td>0.1 µF</td>
<td>–</td>
<td>0603</td>
<td>Samsung</td>
<td>1276-1936-1-ND</td>
</tr>
<tr>
<td>4</td>
<td>POGO</td>
<td>–</td>
<td>Pogo pin</td>
<td>1.85mm dia.</td>
<td>Mill-Max</td>
<td>ED8180-ND</td>
</tr>
</tbody>
</table>

Table A.2: Pogo-grammer BOM
Appendix B

User Guide

Programming:

- Plug TI MSP-FET into computer via included USB cable
- Attach the pogo-grammer to the MSP-FET
- Start applicable programming software
- Orient device and hold on the pogo pins for the duration of programming

Use:

- Affix to wrist as one would a normal watch
- Press either of the side buttons to display the current sun position

Battery Replacement:

- Using a Philips-head screwdriver, unscrew the four case bolts on the back of the watch
- Remove battery from it’s groove in the back compartment and dispose of safely
- Place new battery, positive terminal down, into the battery grove
- Rebuild the part-stack, taking care that the bottom plate cutouts and side switches align
- Re-screw bolts
Appendix C

Technical Drawings

Figure C.1: Top of circuit board

Figure C.2: Bottom of circuit board