UNDP Sentinel

A low-cost platform for daily observation of COVID-19 Community Spread

Problem:

There are vast numbers of people in both developed and developing countries working in long term care facilities, hospitals, and other essential businesses, who should ideally have daily testing for Covid19.

Yet It seems unlikely that definitive biological tests for active Covid19 virus can be practically or economically scaled to enable testing every worker every day in the developed nations of the world and the problem is much greater in the less developed nations.

Clearly testing is particularly important in the medium and low-developed areas of the world where care workers are limited in number, must remain healthy, and not spread the virus to those they are caring for.

What is vitally needed is an open source and quickly replicable product that assists with early identification of people who are either not well or are ignoring symptoms and then target them for biological testing or limit their exposure to vulnerable populations, until it is unlikely that they have or will spread the Covid19 virus.

Our Solution:

Our solution is to develop an electronic "vital signs" prescreening system. This can be done by packaging and integrating already available electronic sensors into an easy to use and sanitize package. This can allow better, targeted testing with the scarce biologic tests by daily screening of workers who are either not recognizing or ignoring mild symptoms while they continue to work. The device will measure multiple vital signs to look for signs of distress. These include, pulse rate, oxygenation levels, temperature, and perhaps, respiration rate.

Much of the world is currently using non-contact temperature readings to indicate that an individual is not well and should be further checked. Experience has shown already that temperature alone is not a particularly early or reliable screen. But it has also shown that non-or- limited contact screening devices that do not need consumable items or delayed laboratory results can have a psychological effect, making people more aware of themselves and their surroundings.

Some front line medical workers like Dr. Richard M. Levitan have observed that many Covid19 infected people present with a very low blood oxygen level without their body noticing it (silent Hypoxia) and have hypothesized that detecting a drop in oxygen saturation (Sp02 decline) is likely an early indicator of infection, perhaps even better than body temperature, especially for persons who may have the most severe reactions to the Corona virus.

But currently available finger clamping pulse/oximeter devices are not easy to share because the design makes it hard to sanitize, and hard to integrate into a measurement and history storing device aimed at screening employees working with vulnerable populations at their workplace as they come in to work.

Sentinel is a low-cost, open-source platform that measures blood oxygen level with a limited contact, easy-to -clean reflective blood oximeter sensor. Combining inexpensive commercial off the shelf (COTS) components, an easily produced 3D printed platform, and standard 3rd party components, such as the Apple® Watch protective screen and a Maxim® reflective sensor this platform would allow easy quick screening of every front-line worker going into and out of a high-risk environment. The use of Raspberry Pi computers also allows keeping a history for each employee's measurements so trends can be monitored. This platform measures blood oxygen saturation and heart rate through a low-contact biometric reading obtained by placing a finger on an easily disinfected reflective sensor operating through a tempered glass screen. The screen is easily sanitized by simply wiping with a cleaning product between uses.

Provisions are made for adding a non-contact IR Thermometer device which could be positioned to read body temperature as the employee stands in the location to use the pulse/oximeter. Although because of lack of supply we have not been able to incorporate a medical grade IR temperature sensor into our current implementation in time for this competition and even nonmedical grade sensors are hard to come by.

Sentinel is designed to comply with the Principals for Digital Development, including simplicity, low cost, ease of implementation, and replicability. The mechanical design of the product makes it difficult to contaminate and easily disinfected with every use.

Rather than a complete saleable platform, Sentinel is purposefully designed to provide key building blocks that can be easily integrated into systems of various form factors and powered in multiple ways that allow it to be adapted to local needs, component availability, and capabilities of Makers and Hacksters of nations around the world.

The team behind Sentinel hopes for the UNDP's assistance to scale up our innovative & open-source solution for a use in some of the most deserving areas of the world.

We hope to study the correlation between the pre-screening indicators of infection offered by the Sentinel platform (blood oxygen saturation, heart rate, and when available temperature) with the results of more sophisticated viral testing. The long-term goal of Sentinel is to understand if we can use these vital metrics together to serve as an early indicator of possible Covid19 infection especially where biological testing is too costly, results are not timely enough to be useful, or where testing is practically unavailable.

We want to facilitate what economists call "natural experiments". By regularly capturing wellness data from a large number of people who undergo regular biological testing in first world countries, we expect eventually, serendipitously, to capture wellness data before and after positive Covid19 biological tests which more accurately identify positive cases. By continuing to follow those cases, and with data before and after biological tests, we hope to develop a statistical picture that will tell us if measurable vital signs might precede self-perceived symptoms or medically recognizable symptoms as Covid related. This information would be difficult to get ethically other ways but would contribute greatly to understanding the infection symptomatic and/or asymptomatic timeline.

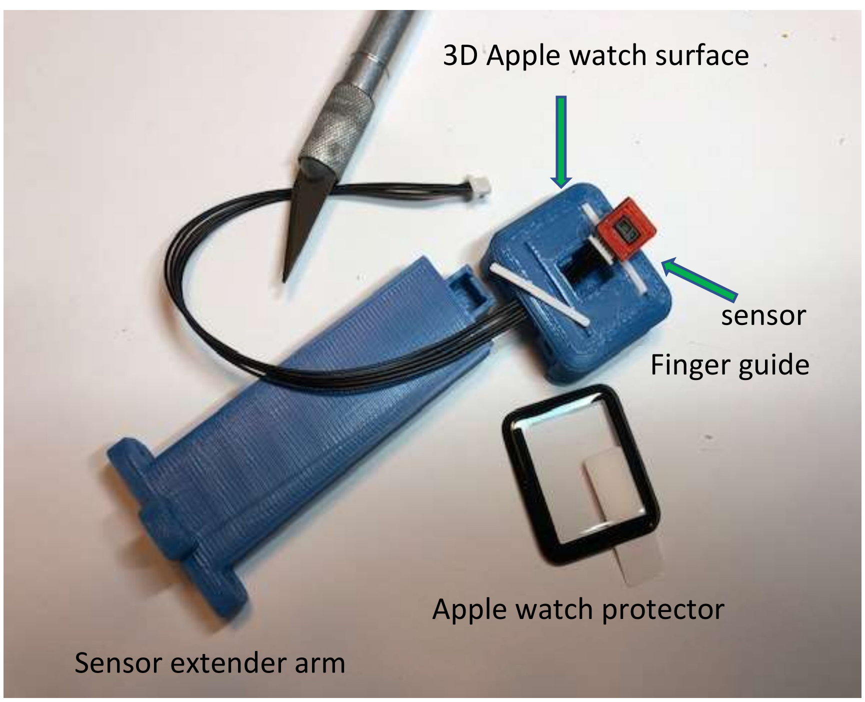
The System:

The key concept in this project is the 3D printing of a package for a reflective Pulse/Oximeter sensor (the MAX30101) in a form that is easy to use and sanitize in a volume screening environment like the reception area of a longterm care facility or an office building rather than a hospital environment. The software for the pulse/oximeter can be implemented on different models of Raspberry Pi computers. Although our first prototype is running on a Raspberry PI 3B+ and a raspberry Pi Zero W the code can be adapted to run on a myriad of Arduino and similar processors available to the Maker/Hacker community by knowledgeable hackers.

The problem to be solved in sharing a Pulse/Oximeter device is to have it be easy to use and readily sanitized. 3D printing offered a way to create a packaging scheme to do this. The key to the solution was to use a very thin tempered glass screen (about .3mm) to cover the sensor so that the sensor function was not impeded by the refraction or attenuation of the cleanable surface. The first thought I had was to use a glass cover like those used to protect cell phone touchable surfaces. But once tempered, the glass is not able to be cut to a usable size. Then I realized that the problem of getting a smaller better form factor glass was already solved by those who were providing similar protective surfaces for Apple® watches.

There are a lot of small boards that are available around the world that hold the Maxim 3010x series sensors and, at a minimum, a voltage regulator to supply the 1.8 volts the sensor needs from a 3.3-5V system power and level translation for the I2C communications interface of the sensor needs to talk to a variety of processors running on either 3.3V or 5V.

After looking a number of alternatives, we settled on a Wireling board AST1041 from Tiny Circuits to use in the design. There are equivalent or slightly different boards from other suppliers like Adafruit, Sparkfun and Maxim Integrated itself and these are available worldwide through distributors like Mouser and Digikey. The Maxim sensors MAX 30100,101,102 even 105 should be usable. There are also many sources listing MAX30102 or clones on eBay.



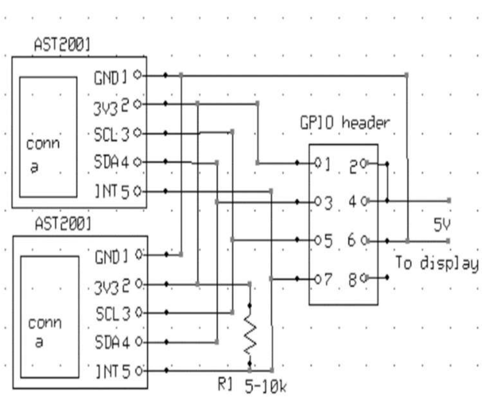
This packaging breakthrough, though, was to model and 3D print a top surface of an Apple® 38mm watch with a deep mounting hole for the Tiny Circuits® sensor board with connector attached. This allows the sensor to be mounted with the top of the sensor a hair above the surface. Then a glass watch protector (e.g. SNSIR 9H available on Amazon®) to cover over the 3D printed top. This key element of the optical path is the very thin glass protector which generally has a coating on the watch surface side of glue that matches the index of refraction of the glass cover on the sensor so that there are no reflections at the boundary. To be sure that this glass to glass connection is well made is the reason for keeping the top surface of the sensor a few tenths of a mm above the surface of the 3D printed watch model. That facilitates the bonding of the watch cover to the glass cover of the sensor, protecting the sensor and minimizing any crosstalk between the LEDs and the photosensor. The glue is not strong enough to hold the glass cover in place, but superglue around the curved outer edge of the cover can hold the watch protector to the 3D printed surface well away from the sensor while the small surface area of the sensor is protected and the whole assembly is easy to sanitize.

The 3D printable oximeter sensor support arm extends the printed watch face surface out far enough from any case holding the computer to allow any finger of either hand to be positioned over the sensor area without the hand touching anything else. The Sensor holder is designed to mount by screws to various enclosures with different Raspberry Pi models or other SOC devices that can run the code to make the sensor work and analyze and display the sensor output. The enclosure for the computer system can then be locally tailored to hold whatever computer and power system is available anywhere in the world.

The sensor body and arm are printed using Copper3D PLActive™ filament https://copper3d.com/ which is filled with copper nanoparticles that makes it unfriendly to viruses and bacteria. The 38mm apple watch surface head is printed separately from the extending arm. Both parts have an interior channel to accommodate using a 200 mm Wireling cable to connect the sensor board to the GPIO of the Raspberry Pi. The parts are designed so that when the Watch top and sensor print and the extender arm print are mated the connector is trapped preventing the cable from being pulled out of the sensor. The 3D parts are also designed to allow the use of two 3mm stainless steel rods to align the two parts and provide additional mechanical strength to the assembly if needed. There are 5 stl files composing the sensor head and two stl files providing a case for the Raspberry Pi 3B+.. We will also provide Autodesk inventor files so that the designs can be modified by those who have a need and the capability to do that. I hope to finish the design of a portable, solar rechargeable unit using a Raspberry PI Zero W processor for use worldwide in locations where a power grid is not always available. Getting all of this is done in the short time of the competition is not realistic. But the Pi 3B+ system will all be available.

All of the parts for this project were printed on a Lutzbot® Mini 2 printer on standard Polylite PLA settings and using Copper3D PLActive™ filament. The 38mm head was printed in using high accuracy settings in Cura, the rest of the parts were printed in Standard accuracy settings. Most of the parts were printed with 100% fill. None of the parts took more than 4 hours to print.

The tolerances are pretty tight for these prints so you may have to experiment with settings and do some post processing with a sharp pointed knife to get things to fit perfectly. The 3D filament does not have to be the one we used, because it is more expensive and in short supply. Any PLA material should work as long as it can be safely cleaned with available sanitizing solutions.



We decided to do the sensor and human interface development work on a Raspberry Pi 3B+ with either a small homemade GPIO connector adapter with two Tiny Circuits Wireling breakout boards or a Wireling PI Hat that provides 4 I2C ports and a real time battery backed up clock. The RTC could be used to provide timestamp of gathered data for an employee database for instance.

The homemade GPIO adapter uses 2 Tiny Circuits AST2001 breakout boards, a resistor with a value between 4k-10k, 1 female 4x2 header connector, one 5 x 1 header strip and a 5 x 6-hole pattern piece of plated through breadboard material. This provides 2 Wireling I2C with interrupt connections into the Raspberry Pi GPIO connector.

Code developed runs on Pi3B+, 4B, and Pi Zero. Other homebuilt ways can be used to electrically connect the sensors to the I2C pins on the Pi. Our implementation uses GPIO pin 7 for I2C interrupts from the MAX30101 chip but this can be moved, but whatever pin is used for the interrupts needs to have a pullup resistor to 3.3V in the range of 4-10K.

The use of the Raspberry Pi allows the system to have added USB devices like bar code readers to identify employees as well as a keyboard and mouse. And with a 32GB SD card installed it has the storage capacity to keep a history of readings so that the normal range of each employee's vital signs can be kept to help identify changes that might indicate the need for further testing. The Pi platforms also allow attaching a keyboard and mouse for inputting data to set up the device. The HDMI, I2C, and SPI outputs on the various PI computers allows use of a wide variety of display devices. The Pi also can wirelessly connect to WIFI and some have Bluetooth as well so that the is a wide range of possible communication paths to extract data from it.

The system can be packaged with a variety of power sources. If power is available from a grid it can use a standard wall wart plug in universal 5V power supply with on/off switch. If battery power is needed it can be done with rechargeable Lithium Ion batteries and a voltage boost board like a Seed LiPo Rider that can charge the battery and boost the battery output up to 5 volts to run the system. The battery solution can also be set up to be recharged with solar panels. This can be a hand held unit with an integrated display that is either I2C or HDMI capable.

Software.

There are a number of resources online that provide example code to run the pulse/oximeter sensor.

We will provide a C code implementation on GitHub https://github.com/sentinel-o2 based on code freely licensed by Maxim® and improved by Robert Fraczkiewicz (see his instructable https://www.instructables.com/id/Pulse-Oximeter-With-Much-Improved-Precision/) also freely licensed that we adapted be run on a Raspberry pi Zero, 3 or 4. Code from these sources can be found at https://github.com/aromring/MAX30102_by_RF

Our prototype Sentinel system for use at Longterm Care facilities packages a Maxim® ML30101 reflective sensor with a Raspberry PI 3B+ computer and 7inch HDMI LCD monitor as standalone wellness screening tool that is easy to use and easy to keep sanitized while at a registration desk in a building entrance location.

Unfortunately, at this time a medical grade temperature sensor we believe the best to use, the Melenix® ML90632D is in high demand and short supply worldwide so without UN support to help the maker/hacker community get access to this device it is not clear that a medical quality non-contact temperature measuring device can be integrated into any system at this time. It is a simple matter to include one in the system when devices are available since they are factory calibrated for the normal human temperature range and provide I2C interface. We could use an older less accurate but somewhat more available device the ML90416 which is not medical grade and is really not accurate enough without individual calibration beyond what the factory provides. At the moment though it seems that IR thermometers are readily available so it is not essential to add that function.

Our hope is that this project will inspire others to creatively package the sensors and electronics in a way that is most useful in non-clinical, heavy use environments, and that making and recording these measurements will ultimately help provide "natural experiments" that give insight into the way Covid19 measurably affects the people in the early stages of infection.

We envision that there is a lot of room for both software and hardware creativity to enhance this "wellness" monitor system. For instance, a lidar or IR PIR could detect the presence of a person and help guide them to the proper position for temperature measurements, an employee database that uses bar codes or RFID technology to allow for touchless ID could be developed, a camera could be added to verify facemasks are being used and perhaps even pulse/oximeter readings that are totally non-contact.

Ideally we can eventually have a completely touchless measurement of vital signs as an adjunct to the more sensitive biological measurements to help detect and protect all of the world's most at risk populations. But until then Sentinel is a new tool that should be useful around the world right now.

Here is what Sentinel would look like on a reception counter

The monitor is a 7 in screen.

Developers:

Sentinel is designed by Robert J. Simcoe retired electronics engineer with deep knowledge of integrated circuits, optics, light systems, and large and small system designs with over 25 patents; Jeffrey Cooper Associate Professor/ Dept Chair Biomedical Equipment Technology at Springfield MA technical community college; Josh Thomas Innovation Officer and US President of Brandwidth; and Steve and Chris Thierauf provided valuable input on the project and help with setting up our GitHub site.

The Sentinel team is not interested in pursuing this as a business proposition; instead, it's focus is on getting these hardware and software building blocks developed, released and distributed quickly into the maker/hacker community worldwide in this time of need. Sentinel will furthermore act as a source of inspiration globally in locations where the UNDP operates, inspiring a generation of young people in many developing countries to consider futures in creative technology and computer science. For good ideas to blossom they are often best given away!

Bill of Materials

For the wellness sensor system

1- 1 - AST 1041 from Tiny Circuits

2- 3 -AST2001 Tiny Circuits breakout wireling boards

3- 1 - 4x2 8 pin 2.54 mm pitch female double row straight header connector

4- 2 – 200mm wireling cable Tiny

5- 1- 4,7-10k 1/8watt resistor

6- 1 – Melenix 90416 temperature sensor

For a model Raspberry Pi computer system

7- 1 - Raspberry Pi 3B+ computer with power supply and heat sinks

8- 1- HDMI Raspberry pi compatible display device

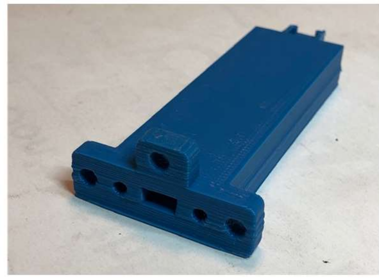
9 1-USB Keyboard and mouse for development

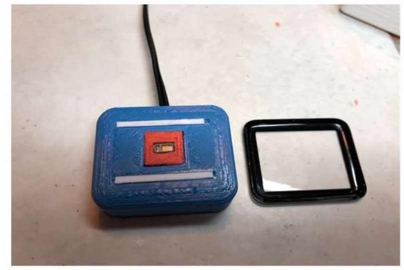
(Files for the project are at https://github.com/sentinel-o2)

3D printed parts

For the reflective Pulse/Oximeter sensor

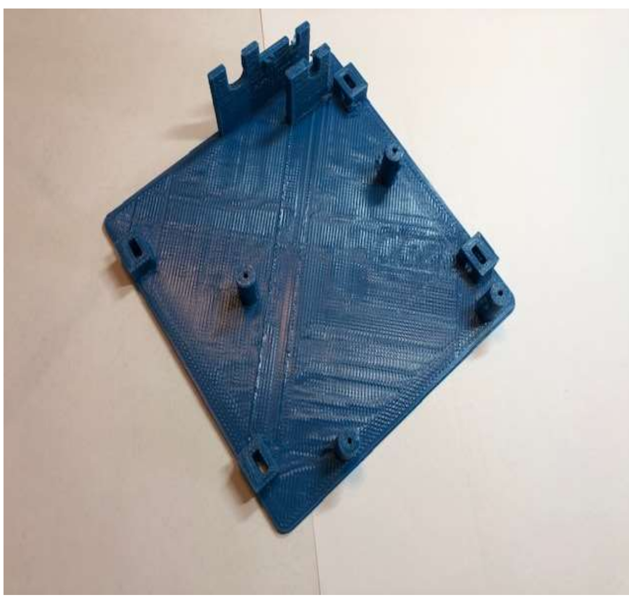
1. The watch head with the modeled top surface of the Apple® 38mm watch.
2. An optional set of finger guides
3. An optional sensor surround (this is to make the sensing area and preferred finger orientation more obvious to the user)

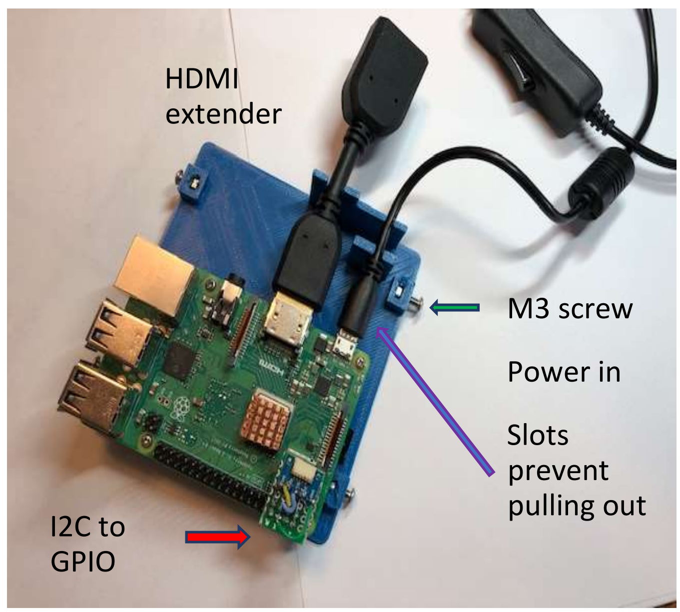


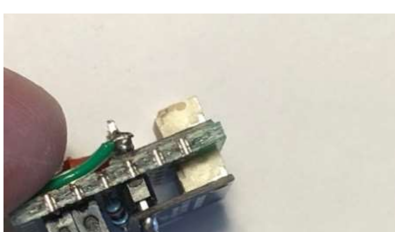


The sensor and arm are the most critical part of the design. The arm can be attached to the computer case detailed below, any commercially available box that the computer will fit, or any other 3D printable enclosure that can be made to be easily sanitized. The arm is long enough to allow any finger on any hand to be measured without contact to the computer case.

For the Raspberry Pi 3B+ case







The GPIO to Tiny Wireling adapter Two I2C connectors one for Maxim sensor and one for temperature sensor

The base that holds the computer with cord capturing slots preventing cord dislodgement

1. An optional HDMI extender (an HDMI cable could also be used if this part is not available)
2. A 5v 2.5-amp USB mini output connector with on/off switch. (standard Raspberry power module)

The top cover fits over the base above.   It attaches by the 4 M3 screws that go into the nuts on the base

Development screen on a large monitor showing readings