Low-Cost Contact Thermometry for Screening and Monitoring During the COVID-19 Pandemic

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***Abstract*—A key component of the UN Sustainable Development Goals (SDG) is goal 3, Good Health, and Well-Being. Fundamental to the accomplishment of this goal is women's health. Pregnant women and women raising infants would benefit from early screening. In socially disadvantaged areas, patients may not have ready and frequent access to formal healthcare or screening solutions. In such instances, simple solutions that allow for self-monitoring can help. Additionally, when provided with devices that promote positive behavior modification such as sensor-enabled wearable devices, other advantages may accrue. Data collection from multiple subjects for screening and contact-tracing may have potential use in the ongoing COVID-19 pandemic and beyond. A low-cost, contact thermometer solution based on a silicon bandgap temperature sensor that allows for personal screening is described using a Proof-of-Concept solution.**

Keywords—UN Sustainable Development Goals, Temperature Measurement, Wearables, Health Trends, Pregnancy, Neonatal Care, Contact Thermometer

I. INTRODUCTION

Within the UN Sustainable Development Goals (SDG), Goal 3, Good Health and Well-Being, several areas of human health have been recognized as having been part of progress, but still requiring acceleration [1]. Maternal Health and Child Health are among the stated areas [2]. Research indicates that maternal health and child health may be linked, with maternal health issues, consequently affecting fetal and child health [3] [4] [5]. The urgency for improvements in maternal health and reduction in mortality has been demonstrated [6]. While the specific effects of COVID-19 on pregnant women are not well understood currently, cautious approaches are recommended in preventive and post-diagnostic care [7].

The focus of the current work is in the demonstration of the feasibility of a low-cost open-source solution for self-care and monitoring for a specific cohort. The solution may be expanded to, include other cohorts and additionally allow for the design of population health intervention using machine learning techniques.

Medically underserved populations [8] would be better served by the availability of innovative, cost-effective diagnostic and monitoring devices [9] with at least an acceptable level of performance enhanced by technological advances in sensing. Maternal temperature measurement and monitoring have been studied and reported in clinical studies [10]. Temperature, a basic vital sign recommended for monitoring during pregnancy [11] is also indicated for pregnant women diagnosed with COVID-19 infection [7].

II. BACKGROUND

A. Project Objectives

The team had the following key objectives while considering the project planning and execution:

1) The solution should serve an underrepresented demographic that requires customizable, cost-effective solutions.
2) In keeping with the general principles of the Maker Movement [12], the design should be open, and open hardware and software should be used whenever possible. Components should be readily available to allow for mass production and distribution.
3) For processing and testing capabilities, an affordable Single Board Computer (SBC) or microcontroller, or preferably, an open-architecture device will be used.
4) The devices should render the highest acceptable screening performance at the lowest optimal cost for widespread adoption.
5) The design should be flexible to be adapted for different implementation styles, such as a handheld versus a wall-mounted device, or a wearable device, and allow for use under varying social distancing protocols.
6) Proof-of-Concept (PoC) solutions that are proposed, demonstrated, and published will aid any team worldwide to seek funding, and make efforts to realize the project's completion, maximizing the chances for success and implementation.
7) The primary objective for the project to be a response to the COVID-19 pandemic, but the solution should be extensible to non-pandemic situations as well.
8) The solution should serve individual end-users, but also lend itself to artificial intelligence techniques for pattern recognition in larger

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populations for incidence and contact tracing, as well as other trends analyses.

9) The primary objective of the device is to function as a screening device, and not as a clinical device. Regulatory approvals and commercialization are currently outside the purview of this work.

B. Temperature Measurement

Body Temperature Measurement has been identified among the vital monitoring and diagnosis parameters for COVID-19. Fever is a key symptom, which, when it manifests, appears 2 – 14 days after infection [13]. Body Temperature Measurement is the basis for the design of a phone application along with analysis and dashboarding tools that use AI to identify infection trends [14].

Fever monitoring recommendations vary largely based on national, regional, and local governments. Notably, frequent temperature measurement is a component of most such recommendations and guidelines [15], [16], [17], [18].

C. Target Population

Non-contact and contact thermometry solutions work on different sets of principles and in the COVID-19 pandemic, both have distinct applications. For instance, non-contact thermometers are used to abide by workplace screening guidelines for which the team has demonstrated a distinct, proof-of-concept solution through [19], guidelines are available for temperature screening for pregnant women diagnosed with COVID-19 [7] and for screening during maternity in general [11], for which contact thermometry might offer pertinent solutions.

D. Types of Temperature Measurement

Body Temperature Measurement can be through non-contact or contact techniques.

1) The two non-contact thermometry device types are

a) Thermal Imaging Systems

b) Infrared Thermometers [20].

2) Contact thermometers use the conduction mode of heat transfer. They are of four types:

a) Thermocouple

b) Resistance Temperature Detector

c) Thermistor [21]

d) Silicon Bandgap Temperature Detector [22]

The various types of thermometers have applications for specific measurement necessities. Their application in human body temperature are discussed in scientific literature [23], [24], [25], [26]. For this paper, in accordance to maximize performance while minimizing cost, the Max30205 [27] was selected for the PoC phase.

E. Non-Contact Vs. Contact Temperature Measurement

Both non-contact and contact body temperature measurement techniques have their applications. To ensure social distancing during the COVID-19 pandemic, non-contact thermometers have been widely recommended [20]. The team has previously designed a PoC solution for low-cost non-contact thermometry [19]. Contact thermometers similarly have specific applications, both in response to COVID-19 and beyond. The key differences are as follows:

1. Non-contact thermometers measure surface temperature, while contact-thermometers may measure internal body temperature, based on the location of measurement [28]. The Max30205 measures surface temperature through contact.
2. When screening multiple humans, such as in retail establishments, schools, factories, and similar locations where human density and interaction is high, non-contact thermometers are preferable to avoid undesirable contact or sharing of thermometers.
3. For pregnant women, the effects of COVID-19 are poorly understood. Having a personal, wearable, or portable contact thermometer will allow pregnant women, and other potential at-risk cohorts to self-screen through non-invasive, skin surface temperature measurements. Non-contact thermometers measure skin surface temperature and accounting for factors affecting contact thermometer-based skin surface temperature measurements [30], for screening purposes, the two modalities are comparable.
4. The contact-thermometer can be continued to use post-pregnancy to monitor the health of the mother and the infant [31]. Skin temperature measurement for infants can be an indicative and screening tool in infant care.
5. Personal thermometers, when not shared with other adults, and only used on self or infants after childbirth can minimize the risk of infection spread.
6. When data collection and sharing options are provided with the device and shared voluntarily by the subjects, it can add to the body of knowledge regarding screening with skin temperature during pregnancy and after childbirth and can be useful during the pandemic and beyond.

F. Device Form, Fit and Function

The contact thermometer can be designed to take different forms, a desktop device, or a wearable device. Both devices have advantages and disadvantages. A wearable device has potential advantages that render it suitable for the current application:

1. In one survey, pregnant women expressed willingness to use wearables during pregnancy for prenatal care [32]. In one study, the use of a wearable for self-care was demonstrated to be feasible during pregnancy [33].
2. A wearable device is portable and allows the subject to perform self-checks regardless of location. A wearable device has a physical footprint that allows for it to be worn and/or carried along by the user. The contact thermometer is intended to be used periodically, and not as a continuous monitoring device.
3. Engagement [34] in self-care and long-term behavior change [35] are potentially possible with wearable use. Women's Health, especially in disadvantaged, underserved, and vulnerable communities is a challenge and wearables can aid in alleviating the quality of life for women in such communities.
4. Wearables can be combined with smartphones to accomplish multiple objectives. Temperature screening data from the contact thermometer can be uploaded to a cloud application with the user's permission to provide data for analysis and further research. The data may be utilized in pregnancy monitoring beyond the COVID-19 mandate to assist in future efforts to alleviate morbidity and mortality during pregnancy. Smartphone applications in general may be indicative of alleviation of other conditions such as gestational diabetes mellitus [36]. Providing low-cost smartphones with multiple applications in conjunction with the wearable may accrue other pregnancy-related health benefits.
5. The team is currently progressing with research on using the wearable as an additional tool for contact tracing [37], independent of a smartphone. It may be used as a supplement to smartphone applications in contact tracing.

III. DESIGN AND CONSTRUCTION

In this section, we describe the first-generation Proof-Of-Concept (PoC) demonstration. All elements of the design, as well as future updates, are available for adoption and modification through an online repository to the scientific community through an MIT License [38].

A. Silicon Bandgap Temperature Sensor

In alignment with the design goals, the Max30205 sensor [27] is relatively inexpensive [39], has a footprint suitable for integration into a wearable form factor, usable with Printed Circuit Board (PCB) designs and is suited for fitness and clinical applications, meeting ASTM E1112 specification in the soldered version [40].

B. Microcontroller

The Xiao Microcontroller [41] based on the Arduino architecture, an open hardware architecture [42], with a list price of $4.90, has a footprint suited for prototyping low-cost designs. The ultimate solution would require a CPU with a smaller footprint, suited for wearable products. The team is currently examining alternatives for replacement.

C. Printed Circuit Board Assembly

Following the selection of key components, a minimal PCBA was designed. OSH Park [43], a low-cost, quick turnaround vendor with whom the team has experience creating other low-cost design iterations was used to manufacture the boards. Three boards were ordered and obtained for $7.55 USD each, and the components were soldered by the team. The design for the PCBA is available for adoption [38], [44]. The PCBA is defined and displayed in Fig. 1 - 4. Table 1 lists key items for the PCBA in a Bill of Materials.

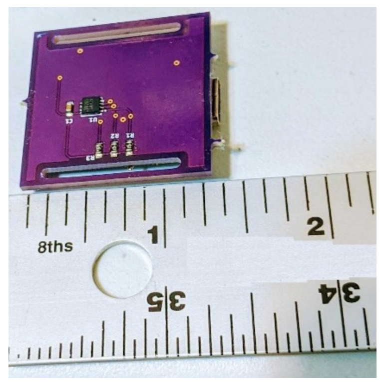

Fig. 1. Fabricated Prototype PCBA for low-cost contact thermometer (bottom view).

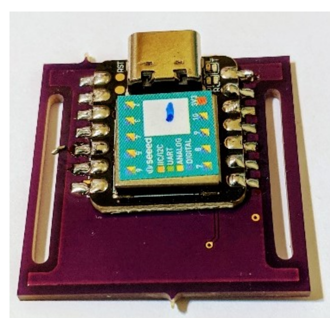

Fig. 2. Fabricated Prototype PCBA for low-cost contact thermometer (top view).

The PCBA was designed to have a small footprint, sufficient for prototyping. The current design has a square footprint, 31.75mm (1.25in) x 31.75mm (1.25in), and a thickness of 28.58mm (1.125in). The design has slots to allow straps to be inserted, and the team has recognized the slot placement, width, and strap selection will be required to be optimized in future designs. This design requires further optimization if a watch profile is preferred when other components and measurement modalities will be added in future designs.

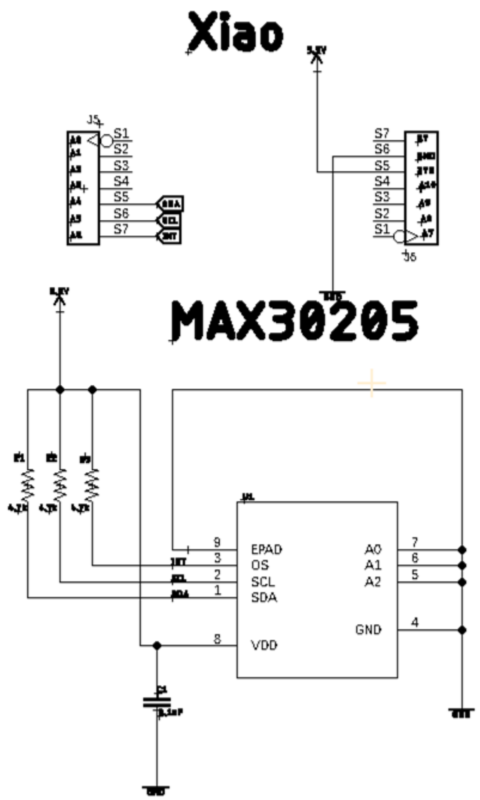

Fig. 3. PCBA schematic for low-cost contact thermometer prototype.

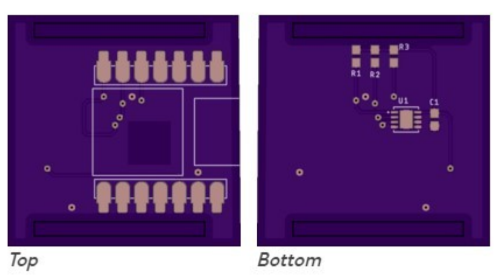

Fig. 4. PCBA Layout Diagram for low-cost contact thermometer

TABLE I. BILL OF MATERIALS - PCBA

Description		
Name	***Part Number***	***Location***
MAX30205 Temperature Sensor	MAX30205MTA+	U1
Xiao Micrcontroller	102010328	J5, J6
0.1uF capacitor	C0603C104Z3VACTU	C1
4.7k Resistor	RR0816P-472-D	R1, R2, R3

D. *Other Details*

The Xiao Microcontroller has a Universal Serial Bus (USB) port which was interfaced with a Personal Computer (PC) to examine the results. In future designs, this will be replaced with Bluetooth connectivity and the wearable will be paired with a smartphone application. The goal is to use coin cells, such as the CR 2032. The Max30205 sensor consumes 600uA during measurement and thus will be required to be switched off and turned on only while making measurements.

IV. DISCUSSION

A. *Results*

Processing [45], the standard open-source tool that can be interfaced with Arduino was used to examine the results of the prototype. The small footprint of the Max30205 produces a challenge when measuring temperature. The goal for the low-cost design is to provide screening, with the aid of surface temperatures.

Oral temperatures tend to be more accurate, however, equipment used orally requires disinfection and cleaning after every use, or the use of single-use, disposable thermometers. Armpit (axillary) and forehead (temporal) temperature measurements are expected to be 0.3°C – 0.6°C below oral temperature measurements, in value [46]. With the Max30205, axillary measurements were seen approximately 1°C below what was observed with digital thermometer measurements in a healthy subject, and approximately 2.5°C below, when measured temporally. Temporal measurements are expected to be the lowest [47]. The results observed by the team were also in line with observations made through a non-contact thermometer designed by the team, where the measurements were consistent, but below body temperature, by approximately the same range [19].

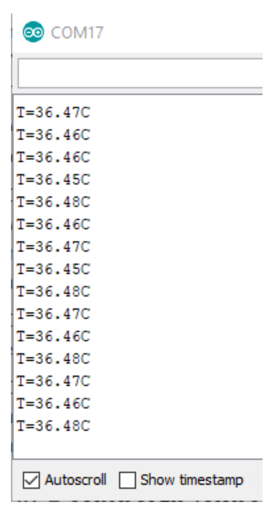

Fig. 5. Axillary Temperature Measurements using low-cost contact thermometer prototype

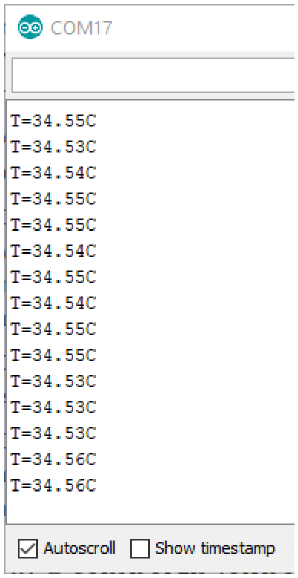

Fig. 6. Temporal Temperature Measurements using low-cost contact thermometer prototype

The measurements are not expected to be clinical, and for screening purposes in a low-cost design setting, the prototype was found to produce acceptable results. The raw data result streams are displayed in Fig. 5 and Fig. 6 for axillary and temporal measurements, respectively.

B. Future Work

The following work is planned for the next phases of the product design:

1) Minimize the overall footprint of the device, and design the product to have a consistent profile, such as that of a wearable and complete housing designs to prototype and test use among volunteer to iterate the design.
2) Through auditory cues such as tones, and visual cues such as light, location, and pressure as well as time to complete measurement. Temperature values or screening results must be displayed in an actionable manner.
3) Identify the appropriate chipset for processing, complete Bluetooth connections and smartphone integration. Explore contact tracing and machine learning capabilities in future application design.

V. CONCLUSION

The proof-of-concept demonstrates that a low-cost contact thermometer solution for screening is feasible. It may be applicable to aid pre-natal and post-natal care. The open design allows for multiple teams to collaborate and scale solutions as desired to combat COVID-19 and routine care during pregnancy and for other cohorts as may become necessary.

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