Automatic Non-Contact Fever Detector to Prevent COVID-19 Spread in Public Places

Katherine Tian

***Abstract:** The COVID-19 virus has spread around the world and over 22 million people were diagnosed with the virus. Fevers are one of the top three symptoms of coronavirus, the others being coughs and shortness of breath. A critical component to prevent the spread of COVID-19 is to quickly detect fevers in public places, including hospitals, doctor offices, elder care centers, schools, gyms, movie theaters, restaurants, etc. Today, thermometers can be used in these places, but they require manual operation by dedicated health workers. To make temperature measurement an automatic process, an automatic non-contact fever detector is developed. The fever detector consists of several components: a clinically tested and precisely calibrated thermometer to guarantee accuracy and reliability, a motion sensor to detect the readiness of temperature taking, a relay-based trigger circuit to replace the manual trigger of the thermometer, and a DC-to-DC regulator to replace batteries in the thermometer. LCD signals and the buzz signal from the thermometer, are used to determine the measurement results. Lighting and sound signals are used as indication of normal temperature or fever. All the functions of the detector are controlled by a microcontroller. The detector has been thoroughly tested for continuous operation. Once widely used, the detector will help to detect fevers in public places and prevent the spread of the COVID-19 virus. .*

***Keywords:** Thermometer, Motion detection, Color detection, Microcontroller, Finite state machine.*

I. INTRODUCTION

The COVID-19 virus has spread in more than 188 countries with over 22 million people diagnosed and over 700 thousand deaths. It is still an on-going pandemic [1]. Although spread is possible before symptoms appear, and from people who do not show symptoms, the virus is most contagious during the first three days after the onset of symptoms [2] [3]. Fevers or chills are listed as the number one symptom of COVID-19 [4]. The other symptoms include coughs, shortness of breath, difficulty breathing, fatigue, muscle or body aches, headaches, loss of taste or smell, sore throats and congestion or runny noses. It is critical to detect fevers in public places to prevent the spread of the virus.

While it is easy to measure a person's temperature using a thermometer, there is no low cost solution to automatically check a person's temperature in a public place without a dedicated healthcare worker. There are large infrared thermo-image based systems available to check for fevers among large amounts of moving crowds in places like airports and train stations. However, these systems are expensive and need dedicated personnel to monitor the images. For places with intermediate crowd traffic, such as in hospitals, doctor offices, elder care centers, schools, gyms, movie theaters, and restaurants, the only way to detect fever is using a manual infrared (IR) based thermometer which requires a dedicated healthcare worker to aim the IR beam, to trigger the measurement and to read the results. This manual temperature taking is done within the six feet of social distance and therefore increases the chance of virus spreading. Furthermore, it takes a lot of manual labor to take temperatures for many people in public places and the dedicated healthcare worker will get tired.

An automatic non-contact fever detector is designed to solve the above issues. The goal is to make the temperature taking a fully automatic process: from detection of a person's position to the readout of the results. The detector is based on an accurate clinically proven thermometer. The design modifies the thermometer and adds extra hardware/software to automate the temperature measurement process. It utilizes a motion sensor to detect a person's position. Instead of a mechanical trigger, it uses a signal relay to trigger the measurement. For the result readout, the system reads the buzz signal and the LCD signals from the thermometer. A microcontroller (Arduino Nano board) is used to control the whole process. In the embedded software, a finite state machine is used to model the process.

The detector is powered by a 12V/2A wall plug-in power supply. There is a 3/8-16 mounting hole under the detector so that it can be easily mounted on a support system, such as a camera tripod.

In the following sections, the technical details of each part of the auto fever detector will be discussed. Section III shows experiment results, followed by discussions in section IV.

II. DESIGN DETAILS

A. Selection of Thermometer

There are two types of human temperature measurement devices: contact and non-contact. The contact-based devices include oral thermometers, tympanic thermometers, and pacifier thermometers [5]. To detect virus-caused fevers in public places, the contact-based devices are not suitable since they are invasive and need close contact. The non-contact measurements include thermal imaging cameras [6] and non-contact infrared thermometers (NCITs) [7]. These non-contact devices need no direct person-to-person contact and therefore are better options for fever detection in public places.

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There are many thermal imaging cameras deployed at crowded places, such as airports, train stations and sporting events. Beside the high cost and requirement of dedicated operators, the thermal imaging-based temperature measurement systems have some limits. Although these systems may be in use for initial temperature assessment to triage individuals in high throughput areas, the systems have not been shown to be effective and accurate when used to take the temperature of multiple people at the same time. The accuracy of these systems depends on careful set-up and operation, as well as proper preparation of the person being evaluated [7].

For fever detection in a public place, NCIT can reduce cross-contamination risk and minimize the chances of virus spreading. The other advantages include being easy to use, easy to clean and disinfect, quick measurements, and able to retake a temperature quickly. However, the close distance required to properly take a person's temperature represents a risk of spreading disease between the person using the device and the person being evaluated [6]. The goal of this paper is to present an automatic non-contact fever detector which overcomes this disadvantage of NCIT. In this paper, the term of "auto NCIT" is used to refer to the automatic non-contact fever detector.

It is important to select an appropriate manual NCIT as the base of the auto NCIT. Although there are many manual NCITs available, not many meet the criteria which include clinically proven high accuracy, well calibration, and quick readout. After a careful search, the iProven NCT-336 non-contact thermometer was chosen [8]. This thermometer was first introduced on the market in early 2019 and has registered with FDA with high accuracy and reliability [9]. It takes temperature from 2 to 6 inches away from the person being evaluated. In addition, the thermometer has a built-in clinically proven intelligent fever indication system. It uses buzz and color of LCD to indicate three possible measurement results: normal, light fever/fever or out of range measurement.

B. Modification of Manual NCIT

After selection of NCT-336 as the base NCIT, the following medications are made to make it suitable for auto operation.

1) Remove of Batteries

NCT-336 is operated with two AAA batteries. For a long-term operation in a public place, the batteries are replaced by a 12V-to-3V DC/DC converter, which is powered by an external 12V wall plug-in power supply. A panel mount switch is used to turn on/off the 12V and it serves as the main on/off switch of the auto NCIT. With this modification, no battery change is needed for a continuous long-term operation.

2) Trigger Modification

NCT-336 requires the operator to point the IR beam to the forehead of a person and push a button to trigger the temperature measurement. In the auto NCIT, a motion sensor is used to determine if the person being evaluated is ready to take the temperature. A signal rely is used to trigger the measurement.

3) Fever Indication

NCT-336 uses both sound and light signals as indications of measurement results. The sound signal is from a buzz inside the thermometer. However, the buzz sound is too small. The auto NCIT picks up the sound signal, interpolates it and generates an 85dB signal using a buzz located on the top of the detector. People 60 feet away can hear the sound.

Another result indicator of NCT-336 is the LCD color. It uses green, yellow and red to indicate normal, light fever and fever. If the temperature is out of range of human's forehead temperature (too high or too low), the LCD also shows red. The auto NCIT uses a color detector to measure the LCD color.

The sound signal and the LCD color signal are combined to get the result of the temperature measurement. These two signals are complementary and support each other. Since the auto NCIT is focusing on the qualitative result, i.e., fever or normal temperature, the detailed temperature values are not read by the detector. If a fever is detected, the quantitative value of the temperature can be confirmed by a following up doctor visit to check the cause of the fever. The goal of the auto NCIT is reliable detection of fevers with no false or missing alarms.

C. Technical Details of Each Function Block

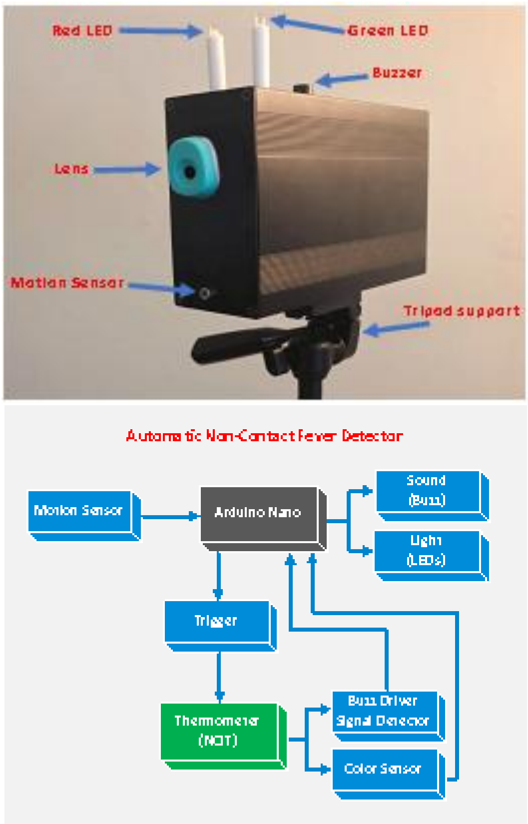

Fig. 1. Picture and block diagram of an auto NCIT.

Figure 1 shows the function block of the auto NCIT. Besides the thermometer discussed in the above paragraphs, the detector includes motion detection, trigger circuit, buzz signal readout, color detection and microcontroller.

1) Motion Detection

When a person gets temperature measurement, he or she will walk to the detector and stand still for 3 seconds with his or her forehead 2-6 inches away from the thermometer lens. After detecting no motion in 3 seconds, the measurement is triggered and the indicators (buzz and LEDs) will indicate the result accordingly. The person then leaves the detector and the next person can take the measurement.

To detect the readiness, a passive infrared (PIR) motion sensor is used to detect the person's motion. The PIR measures infrared (IR) light radiating from objects in its field of view. The IR light causes a small temperature increase of the thermal sensors in the PIR sensor. Often additional lens array is needed to the focus a motion in a distance. In the PIR sensor, it is also important to produce control circuits that take the lowest quiescent currents possible [10].

A lensless PIR sensor is selected for the auto NCIT detector. Comparing with PIR with lens, lensless PIR is smaller in size but has a shorter motion detection range. In the auto NCIT, there is no need to detect motion in a distance or with a wide angle. On the contrary, the auto NCIT needs a short detection range and narrow angle when the person approaches it. Based on these considerations, a Panasonic lensless miniature PIR, EKMC1600100, is selected as motion sensor. The motion sensor has a detection distance of 5m and a digital output. When a motion is detected, a TTL high pulse is generated from the sensor. When the motion stops, the TTL signals goes to low.

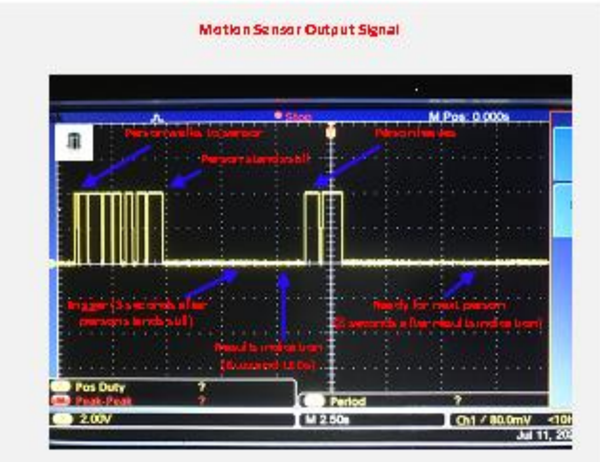

Fig.2. Lensless PIR motion sensor output signal.

Accurate detection of a person's movement is critical for the auto NCIT. Figure 2 shows the output signal of the motion sensor during the automatic temperature measurement process, which consists of a person walking to the sensor, standing still for a few seconds, and leaving after the temperature measurement.

2) Trigger Circuit

As a typical thermometer, NCT-336 uses a mechanical push button to trigger the temperature measurement. In the auto NCIT design, the trigger is automatically generated after the motion sensor detects the person is standing still.

The NCT-336 uses the mechanical bush button to generate a TTL signal. When the push button is pressed, the pull-down resistor is connected to +3V and generates a TTL high signal. This circuit can be easily replaced by a signal relay, such as Panasonic TXS2-L-1.5V. The trigger signal, which controls the open/close of the relay, is generated from the Arduino Nano microcontroller.

3) Fever Indication Readout

The NCT-336 has a built-in intelligent fever calculation and indication system. It is a clinic proven system. For the auto NCIT, there is no need to repeat the fever calculation. Instead, the indication results from NCT-336 thermometer are directly read out.

The first result from the thermometer is sound signal from an internal buzz. The sound signal is very small and hardly audible even in close distance. Inside the thermometer, the buzz signal is driven by a MOSFET gate signal. In the auto NCIT, this gate signal of the MOSFET is connected to the digital input of the Arduino Nano microcontroller. The software reads the gate signal and gets the results. There are three possible patterns for the gate signal: normal forehead temperature (93.3oF to 99.4oF, or 34.1oC to 37.4 oC); light fever (99.5oF to 100.5oF, or 37.5 oC to 38.1 oC) and fever (100.6oF to 108 oF, or 38.1oC to 42.2 oC); and out-of-range temperature (less than 93.3oF or higher than 108oF, or less than 34.1 oF or higher than 42.2 oC). The out-of-range temperature usually happens when the sensor of the thermometer doesn't point to the forehead. For example, if it points to the person's hair.

The second result from the thermometer is the LCD background light signal. The thermometer uses green, yellow, and red background light as indication of normal, light fever, or fever. The thermometer also uses the red color as the indication of out-of-range temperature measurement. In the auto NCIT, a color sensor, RB-Prr-17, is mounted on the back of the LCD screen to measure the color of the LCD color. The key part of the color sensor is the TCS230 programmable color light-to-frequency converter. There are four TTL mode selection pins on TCS230 for the selection of red/green/blue photodiode. The microcontroller sequentially selects the photodiode and measures the frequency output signal. It then uses the values for different photodiodes to determine the color of the LCD background light.

It is worthy to mention that the built-in intelligent fever calculation from the NCT-336 thermometer is not changed. Therefore, the auto NCIT automates the process of temperature measurement without losing accuracy or reliability of the NCT-336 thermometer.

4) Alarm Indicators

The auto NCIT uses two LEDs (red and green) and an 85dB buzz as indication of the results. The LEDs and buzz are mounted on the top the detector. To enable the driving capability, MOSFET is used to drive the LEDs and buzz.

5) Microcontroller

To meet the small size and low power requirements, an Arduino Nano microcontroller is used to control the entire fever detection system. The microcontroller has 14 digital IO, 6 analog IO and 32KB flash memory. It has a compact size of 18mm x 45mm. The Arduino integrated development environment (IDE), a free cross-platform development tool, is used for software development.

6) Embedded Software Design

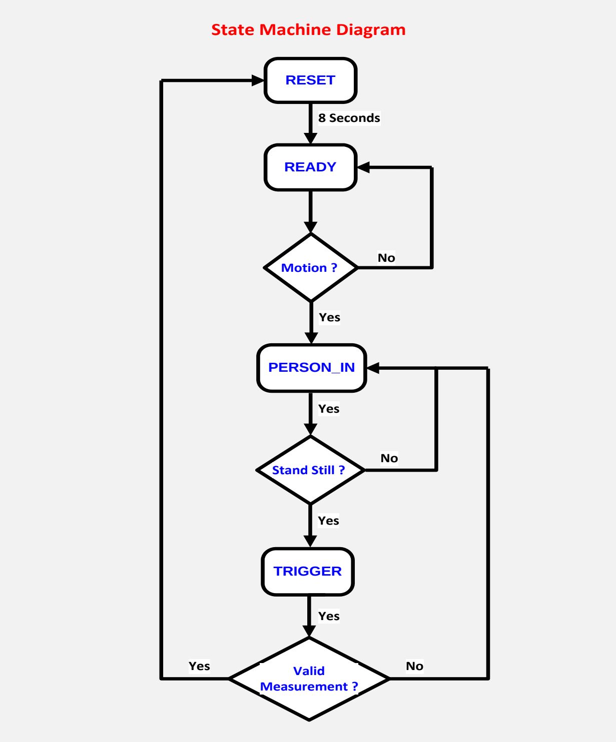

Fig.3. Finite state machine diagram.

From motion detection to fever indication readout, the whole process is controlled by embedded software running on the Arduino Nano microcontroller. The software is written in C language.

The automatic temperature measurement is a repeating process. The finite state machine is a suitable mathematical model for the software development. Figure 3 shows the different states in the process, including RESET, READY, PERSON_IN, TRIGGER states.

The detector goes to RESET after it finishes one measurement. It stays in RESET for 8 seconds for the person to leave. Then the state transfer to READY state in which the detector is ready to take next temperature measurement. In READY state, any motion movement will bring the state to PERSON_IN state, which indicates that a person is approaching the detector. In PERSON_IN state, the system waits for the motion to stop for 3 second as the person stops movement. Then, the system transfers to TRIGGER state.

In the TRIGGER state, the signal relay is closed to trigger the NCT-336 thermometer. It then checks the internal buzz signal and the color signal from the thermometer to determine the result. If a normal temperature is detected, the green LED lights up and the buzzer sends a short sound. If a light fever or fever is detected, the red LED lights up and the buzzer sends a long sound. Both normal and light fever/fever results are valid measurements. The state will transfer to RESET state after these valid measurements. The third measurement result is an invalid measurement. The thermometer obtains a too high or too low, i.e., out-of-range, temperature reading. This usually happens when the person's forehead is off the sensor of the thermometer and thus the thermometer gets an abnormal temperature. For an invalid measurement, the red LED blinks and the buzzer beeps three time to remind the person to adjust their position and retake the measurement. The state transfers to PERSON_IN state. After the person stands still for 3 seconds, the thermometer is triggered again for a repeat measurement.

III. EXPERIMENTAL RESULTS

Even though the thermometer selected (NCT-336) in the auto NCIT is clinically proven to have high accuracy and high reliability, extensive experiments have been done to verify the overall accuracy and reliability of the auto NCIT.

A. Experiment Setup

It is not convenient to test the fever detector on people. To verify the performance of the auto NCIT, a precise temperature-controlled object is used to simulate a person's forehead temperature. A seedling heat mat with a precise temperature controller was chosen for the test. The mat heats a small Aluminum box, on which a thermos sensor measures the surface temperature and sends its reading to the temperature controller for feedback control.

The temperature controller can set the target surface temperature of the Aluminum box in the range of 68^{o}F to 108 ^{o}F with accuracy of +/- 0.1^{o}F. At each different controlled temperature, the Aluminum box is brought to 2-6 inches from the sensor of the auto NCIT. The auto NCIT results, i.e., red/green LED and buzz, are recorded to compare with the target temperature setting.

B. Test Results

Table 1 gives the experiment results. The discrepancy in the range of 99.0oF to 100.0oF occurs when the target temperature is set to 99.5oF (37.5oC), which is the boundary between normal and light fever temperature. The auto NCIT's measurement is 99.4oF (37.4oC) and doesn't generate alarm indication. Since the test system has an accuracy of +/-0.1 oF and the manual NCIT (NCT-336) is well calibrated, the root cause of this discrepancy is from the resolution and accuracy of the measurement systems.

Similarly, when the target temperature is set to 93.3oF(34.1oC), the auto NCIT reads 93.2oF(34.0oC) and generates out-of-range (too low) alarm. This is the cause of the two discrepancies in the < 95 oF measurement. Similarly, the resolution and accuracy of the measurement can explain the two discrepancies.

Table 1. Experimental result of auto fever detector.

Temperature (^{o}F)	Temperature (^{o}C)	Matched Results	Discrepancy
< 95.0	< 35.0	18	2
95.0-96.0	35.0-35.6	20	0
96.0-97.0	35.6-36.1	20	0
97.0-98.0	36.1-36.7	20	0
98.0 – 99.0	36.7-37.2	20	0
99.0 – 100.0	37.2-37.8	19	1
100.0 – 101.0	37.8-38.3	20	0
101.0 – 102.0	38.3-38.9	20	0
102.0 – 103.0	38.9-39.4	20	0
103.0 – 104.0	39.4-40.0	20	0
>104.0	>40.0	20	0

IV. DISCUSSIONS

If the auto NCIT is facing moving crowd, it might detect a passing-by person and enters PERSON_IN state. Since the person doesn't stand before the thermometer, there is no motion detected. The auto NCIT enters TRIGGER state and generates false trigger. The result is an out-of-range false alarm. This issue can be easily fixed by moving the auto NCIT in a direction where there is no IR source radiating IR light into the thermometer sensor. For example, the auto NCIT can simply face a wall and there will not be any human movement between the wall and the detector unless a person needs to take a temperature measurement.

The handheld NCIT has been used for many years. During COVID-19 pandemic, it is especially useful for fever detection due to its non-contact feature. It has a higher accuracy than the infrared image-based systems. However, a NCIT measurement is still a close-distance manual operation. During the pandemic, or when society is re-opening from the pandemic, it is important to automatically and remotely detect fevers in public places, especially for close-space places. Therefore, a low cost, auto non-contact fever detector is helpful to prevent the spread of virus.

There are many NCITs with high accuracy and high reliability. With some simple and low-cost modifications, the temperature measurement can be changed to an automatic process. The auto NCUT discussed in this paper adds about 20% of the cost of a good manual NCIT (NCT-336). The cost will reduce more for a mass production. The accuracy and reliability of the auto NCIT is determined by the selected manual NCIT. The additional test of the auto NCIT proves its high accuracy and reliability.

V. CONCLUSION

A low cost auto non-contact fever detector automates the temperature measurement process. The detector not only detects a fever but also sends alarm signals to indicate that a fever is detected. It prevents close distance contact during temperature measurement. Once widely deployed in public places, it will help to fight the spread of COVID-19 virus around the world.

ACKNOWLEDGMENT

As a high school student on Long Island, New York, one of the hardest hit regions by COVID-19, I came up with this auto fever detector idea during the three months of shield-in-place at home. Much of the knowledge used in this design came from my high school classes, especially Mrs. Stuart's Physics C class and Mrs. Peraria's AP Computer science class. Also, acknowledgement goes to my parents for their support.

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AUTHORS PROFILE

Katherine Tian is a high school student at Ward Melville High School, Setauket, New York. She likes to solve real life problem with the science and math she learned in school. During the COVID-19, she witnessed the discrepancies between advanced technologies and some simple need of health care supplies. She will dedicate her time to applying technology to improve our daily life.