AC 2011-2830: A DESIGN FOR LOW COST AND SCALABLE NON-CONTACT FEVER SCREENING SYSTEM

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A DESIGN FOR LOW COST AND SCALABLE NON-CONTACT FEVER SCREENING SYSTEM

Abstract
Scientific advancements in multiple disciplines of engineering can be applied to a variety of industries, including defense, aerospace, and medicine. In the modern healthcare industry, for instance, biomedical engineers working with a multidisciplinary team can provide solutions to physicians to aid in disease diagnosis. In a situation such as flu pandemic it may be desirable to do rapid screening for fever detection. In an academic setting, fever screening can help in separating normal healthy students from those with suspected fever. This is the motivation to design and develop an easy-to-use low cost temperature measurement device. The objective of this multidisciplinary project is to design a low-cost, scalable, rapid, and effective device for fever screening that can be applied to a wide variety of situations, such as, classrooms or laboratories during a wide-spread flu pandemic. The project is also aimed at ensuring that the student learning leads to many of the standard outcomes. The proposed design is divided into four sections: Measurement, Control, Communication, and Monitoring. The sensor selected for the Measurement implementation is a medical grade version of the Melexis MLX90614 series of smart infrared temperature sensors. Two Texas Instruments MSP430 microprocessors are selected to implement Control and Monitoring. Communication is implemented using an 868 MHz wireless network. For laboratory testing of the proposed fever screening system, the temperature sensor is mounted on a gantry at the entrance to a lab or lecture hall and the students walk through the gantry sequentially. When a high temperature suggesting fever is measured, an alarm will sound alerting the person controlling the entrance to divert the suspected student to go to infirmary for further testing. The temperature measurement is also done with a mobile temperature scanner to screen students in line at various entrances to the lab or lecture hall. Preliminary testing has validated the feasibility of the proposed fever screening system in the mobile sensory mode. The educational aspects of this multidisciplinary project based on experimentation and lab-oriented studies are demonstrated, and the learning outcomes are promising. In conclusion, this undergraduate laboratory-developed system, applied to multidisciplinary fields shows the feasibility of fever screening in a small to medium scale subject cluster and supports the lab teaching pedagogical approach for multidisciplinary lab-oriented studies.

Introduction

Numerous exciting scientific and technological advancements occur in multiple disciplines of engineering that find application in a variety of industries, including defense, aerospace, and medicine. For example, advancements in sensor technology, wireless hardware design, wireless networks, low power and low-cost microcontrollers can lead to an innovative application to solve a medical problem: how can the spread of a flu virus be prevented in a simple, fast, economical, and efficient manner? This task needs to be carried out with minimal impact at a venue such as a classroom or a lab to insure the goal of screening students for a high temperature related to flu symptoms. This paper explores at the undergraduate level an innovative multi-disciplinary solution for a prototype of a low cost and scalable non-contact fever screening system.

Background

Temperature measurements can be made by contact or non-contact methods. Using a contact method requires using a measurement device such as a thermometer in contact with the person. This is subject to delays while the thermometer absorbed enough heat to stabilize to a constant reading of up to a half a minute. The non-contact methods measure the heat radiated from the person by reading the frequency of the heat. This is considered a fast method as readings are available in microseconds.[1] Additional information about the science of temperature measurement is given in the Appendix.

Overview of proposed fever screening system

A medical-grade infrared sensor is connected to a low-cost microcontroller to detect temperature readings. The microcontroller is capable of wireless communications. A wireless network connects all the sensors (via their wireless microcontroller) into a star network where one master node maintains a connection table that is transparent to the users. One node is used for the display of temperature readings via a wireless, programmable watch display which would be worn by the system operator. This would permit the operator to move around while monitoring the system. A second node is used to interface the wireless network with a computer via a USB connection for control, data collection and time stamping functions for the system. The sensors can be fixed in a stationary location such as on a gantry located at an entrance or used as a mobile unit. Because the network of wireless sensors can expand from one up to 128 addressable units the system is highly scalable. The stationary units are configured to turn on an alarm feature when a temperature in the fever range is detected. This makes them useful for entry point temperature monitoring into an enclosed space such as a classroom or lab. The microcontrollers are all battery powered that utilize sleep modes for extended life. The stationary units can be woken by an external signal such as a motion detector to take a reading while the portable unit would be manually triggered by the operator to take a reading. The wireless watch display and the mobile unit can be configured to operate in a peer-to peer networks or talk to each other via the star network. A graphical representation of the proposed screening system with the stationary, mobile, and programmable watch is shown in Figure 1.

Infrared Sensor

Wireless μc

Programmable
wireless watch display

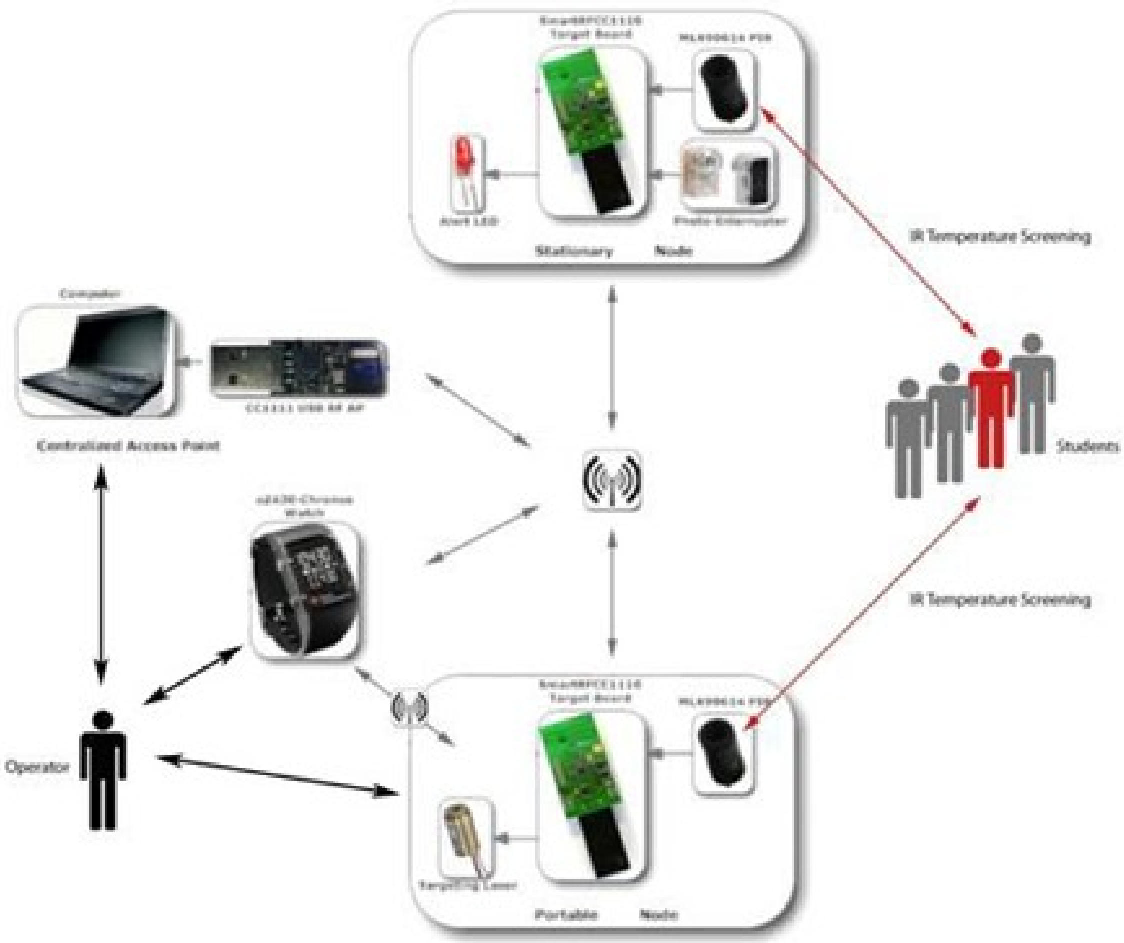

Figure 1. Overview of the proposed temperature measurement system with constituent modules.

Hardware design for the proposed screening system

The three distinct microprocessors used in this project are i) the eZ430-Chronos watch uses a TI CC430F6137 microcontroller, ii) the stationary and mobile units use a CC1110F32 MCU that is an 8051 microprocessor, and iii) the infrared sensor uses an ASIC microcontroller, MLX90302.

The operation of the system is divided into four sections: Measurement, Control, Communication, and Monitoring. Measurement consists of taking temperature measurements using a compact and non-contact temperature sensor suitable to give fast response required in the design. The sensor selected for the measurement implementation is a medical grade version of the Melexis MLX90614 family of smart infrared temperature sensors. Control and Communication encompass initiating/reading temperature measurements and transmitting them wirelessly to monitoring equipment. Monitoring is comprised of wireless data collection, organization, interpretation, and fever indication. Two Texas Instruments MSP430 microprocessor based evaluation boards were selected to implement control, communication, and monitoring: a TI CC1110 Mini DK development board to connect to the Melexis sensor and a TI EZ430 Chronos wireless development tool for the mobile unit. Unique features of the evaluation boards include wireless communication, a LCD display on the EZ430-Chronos, customizable LED's, and a serial-to-USB converter. All the different components are tied together using a SimpliciTI star network or a peer-to-peer network.[2]

The control portion of the operation begins when the wireless microcontroller wakes from the sleep mode by an external signal. The sensor nodes go into a low power mode once the units have been configured and a motion detector is used to wake the stationary nodes and a manual trigger switch is used on the mobile unit. Upon waking the purpose is to take a reading thus beginning the measurement portion of the operation. The sensor module and the wireless microcontroller are connected to each other using a 2-wire bus. The Melexis sensor uses a System Management Bus (SMBus) and the MSP430 uses an I^2C bus (Inter-Integrated Circuit, a single-ended serial data bus). Since the SMBus is a derivative of the I^2C bus with some hardware commands on the MSP430 both units can be made to talk to each other.[3] Both the sensor and the microcontroller have built-in units that handle the data communications between the two modules.

Infrared Sensor

The Melexis MLX90614DCI infrared sensor contains an on-board microcontroller, the thermopile detector chip, RAM and EEPROM memory, and a signal condition circuit. The signal conditioning circuit contains an amplifier, a 17-bit analog to digital converter and a digital signaling processing unit. The Melexis has a low power mode so the wireless microcontroller's first task is the wake the sensor. Since the sensor was configured during the initial setup, it will take a reading and store the temperature value in the RAM location of the sensor's microcontroller unit after passing through the signal conditioning circuit.[4] The wireless microcontroller reads the sensors memory by requesting the on-board microcontroller to send the data via the I^2C bus. The wireless microcontroller then evaluates the temperature data. If the temperature exceeds the set point, 100.4ºF,[5] the wireless microcontroller will send out an alarm signal on the wireless network alerting the operator. For the mobile unit, the actual data is sent over the wireless network to the eZ430 Chronos watch for display. Once the values are read, the devices will return to sleep mode. Additionally, the sensor has a 5º field of view using a lens and the temperature measurement is accurate down to .01º C.[4] Because of the I^2C bus that the sensor uses to communicate with the wireless microcontroller, more than one sensor can be connected to each stationary node. This allows even greater economy of scale by using one wireless microcontroller at each entry point to control multiple sensors.

Data recording takes place and time stamping the information at the PC node which is linked wirelessly to all the end devises using the SimpliciTI star network. The two networks work independently of each other. Software installed on the PC would allow further information collection and reporting. The design of the PC portion of the system is not described in this paper. The Chronos watch display also serves as a control point to operate the system.

Field of View

The most important component in the design is the temperature transducer, for it is directly responsible for taking temperature measurements. Furthermore, the transducer is the most significant factor relating to the accuracy and range of the system. The accuracy of an infrared temperature sensor is strongly affected by its Field Of View (FOV), which is a description of a circular spot on the target's surface. The FOV is given in degrees of the arc inscribed around the normal to the center of the spot. The temperature the sensor generates is the value averaged over the surface area seen by the sensor. In general, it can be said that the smaller the FOV, the better the accuracy of the temperature reading. The formula for the FOV is $FOV° = 2*\tan^{-1}(d/f)$, where (f) is the distance to the target, and (d) is the diameter of the spot.[6] Using the Melexis MLX90614-DCI whose FOV is 5º the circular spot from 23 inches away is 1 inch in diameter. Halving the distance divides the diameter in half. More information on the various devices and their development boards are available in the Appendix.

Software Control

Extensive software programming was undertaken for this system including implementing the SimpliciTI network on the 868MHz stationary and mobile units, writing programs for initializing the sensor then controlling the requesting of data from the sensor and passing the data to the network, adding a temperature application to the Chronos watch display, and writing the peer-to-peer protocol. The wireless microcontroller software flow is shown in Figure 2.

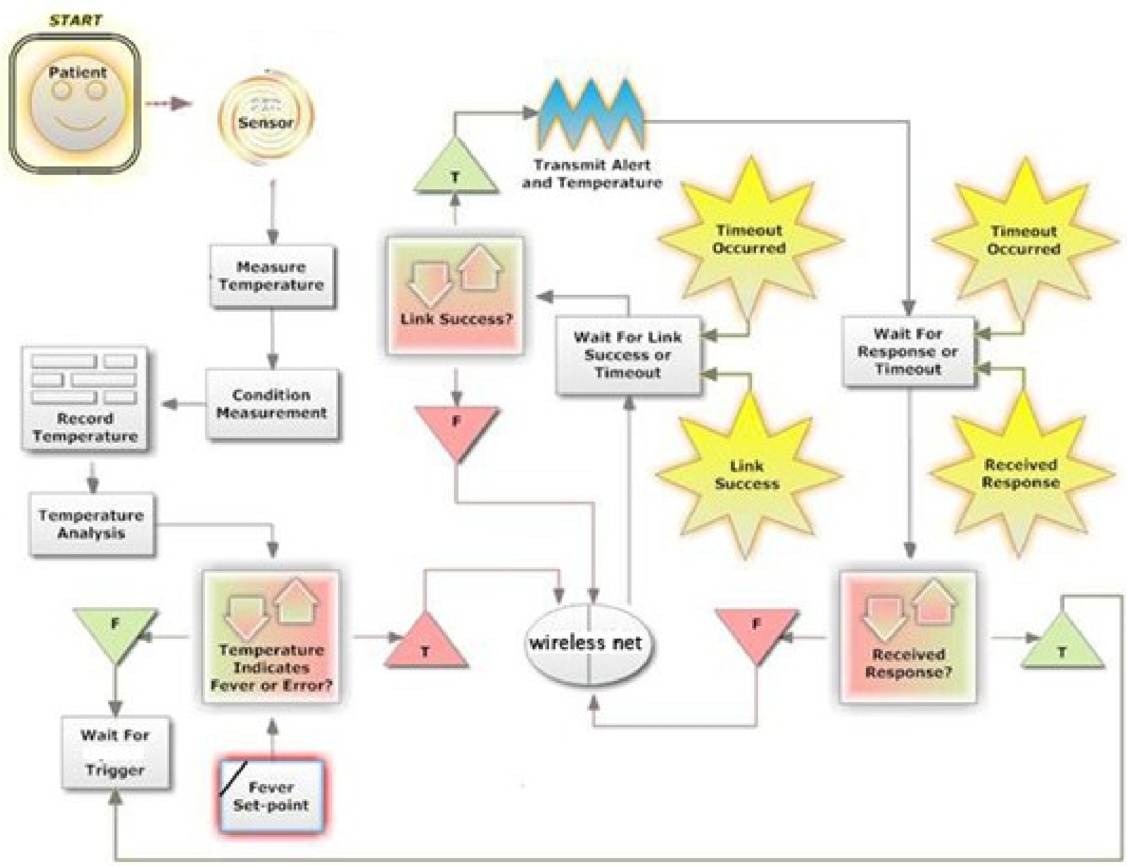

Figure 2. Wireless microcontroller software flow.

Industrial design aspects

In the present project, special effort was made to include team members from different disciplines. One of the disciplines was Industrial Design whose practitioners give form and function to objects. This creative science utilizes knowledge of the arts, technology, social science, business, and a wide range of problem-solving and communication skills. In this collaborative, interdisciplinary product development environment, the role of industrial design is to understand the design requirements and propose a unique, aesthetic, ergonomic and implementable product design solution. The user-centered industrial design process approach is accomplished in three phases, which are (a) design research, (b) ideation and (c) refinement.

(a) Design research builds the foundation of knowledge necessary to create a successful product that meets the needs and desires of stakeholders. This knowledge leads to product opportunities and design criteria. The design research phase is currently underway. The engineering team has developed a wireless technology device, the size of a portable handheld unit. The handheld device consists of a sensor node, which contains the board, an IR sensor, and a small battery. In order to take a temperature reading it is necessary to point the IR sensor in the direction of the subject to be scanned. By pushing the confirmation button a temperature reading is activated and the information is transmitted.

The hand-held portable temperature scanner needs form that allows perfect interaction of the user and the device while repeatedly accomplishing the temperature scanning process. The goal of design research is to understand the needs and desires of the stakeholders.

The project team members have identified the stakeholders as R&D (Engineering, Industrial design), System operator, and Subjects to be scanned for fever screening. Handling temperature readings in a large gathering is anticipated. In order to understand the operational needs, the functional overview of the operator requirements is necessary. A generalized design approach in terms of human factors is necessary to cover this broad spectrum. A wide range of hand sizes and various levels of hand strength should be considered. The interdisciplinary R&D team currently is planning a qualitative focus group to deepen our understanding of the potential operator. The hand-held portable temperature scanner has to be low cost, lightweight, easy to hold and to use and reliable during its lifecycle.

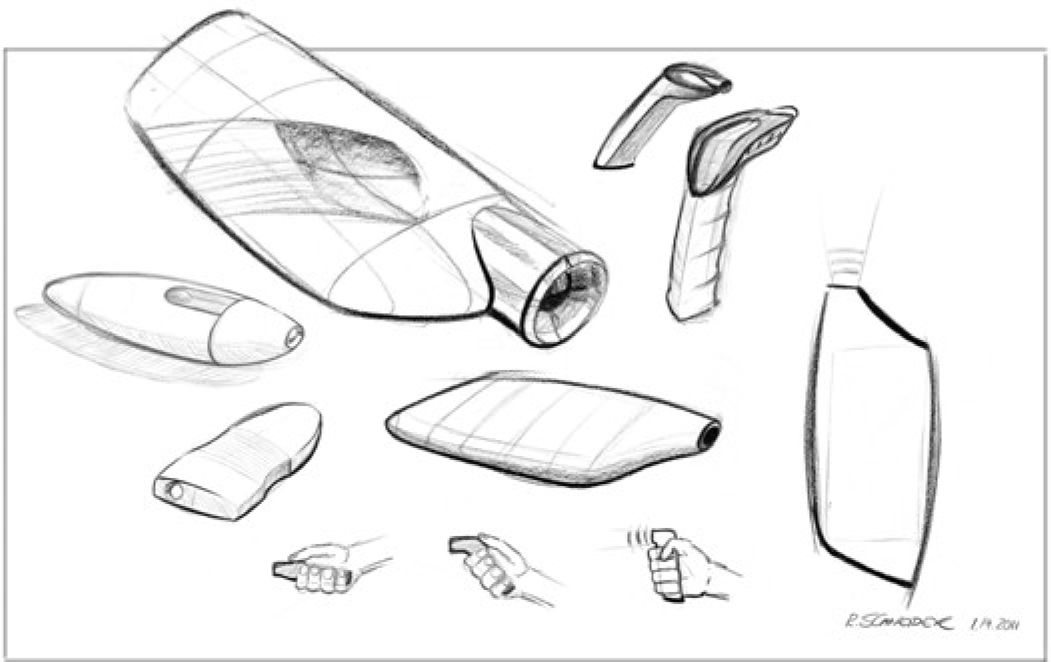

Figure 3. Sketches of enclosure designs for sensors in portable and stationary modes.

(b) In the Ideation & Prototyping phase, the industrial design team is responsible for creating ideas that meet the design criteria. During this process ideas are created, rated, validated and refined utilizing 2D sketching and 3D rapid prototyping. An active exchange of ideas with the engineers is paramount during this phase. The ideation phase is planned to take place after successful testing of the designed system with refinement developed during a collaborative engineering and design team meeting.

Collaborative project update meetings are crucial at this point in the development process to ensure that the team stays on target and is kept updated with the latest knowledge. The design team presents possible design solutions to the engineers and the engineers communicate the latest soft and hardware developments. It is important that this interaction has the intention of inspiring each other to reach the next level of sophistication and provide learning.

At the beginning of the ideation phase, the team reviews the process of taking a temperature reading with the current hard and software and the design criteria. This is where the creative process starts: Taking a thorough understanding of the problem and materialize possible solutions. Many questions are asked such as: How do you hold something comfortably and intuitively point it in the right direction? Are there similar products that must achieve comparable results (e.g. TV remote control units)?

The next step is to create design variations. Two-dimensional comprehensive visualizations along with hand carved foam models (rapid prototyping) communicate the design intention. The given hardware dimensions and product use scenarios will influence the form. Since this temperature-reading device is handheld, special attention to human factors is attributed. The industrial design success criteria is to create a product that effortlessly fits the hand and allows the user to comfortably activate a temperature reading while pointing the IR sensor in the right direction. The ideas are validated and narrowed down to three variations for further consideration.

(c) Concept testing, refining and crafting detailed, functional design prototypes are the tasks in the implementation phase. During the implementation phase three functional design prototypes will be deployed for refinement. The use of 3D surfacing software in conjunction with CAD rapid prototyping will simulate manufacturing requirements and allows for detailed solutions. A user panel will be established to simulate real world prototyping tests. The voice of the actual user as a means of qualitative user research will be an important tool to refine the prototypes. A rating system will be used to draw conclusions on which prototype presents itself as the best solution. The goal is to create a convincing, working product design solution.

Testing

Testing of the prototype has been ongoing during development stages with an objective to do verification of the software, hardware, and network functionality. The method used to verify that the network was working correctly and that the correct data was being sent over the wireless links consisted of the CC Debugger attached to a spare CC1110 board. The spare CC1110 board detects the wireless signals being sent between the active CC1110 board and the Chronos watch. This data is passed to the attached CC Debugger which then presents the results in software via the USB connection on the PC.

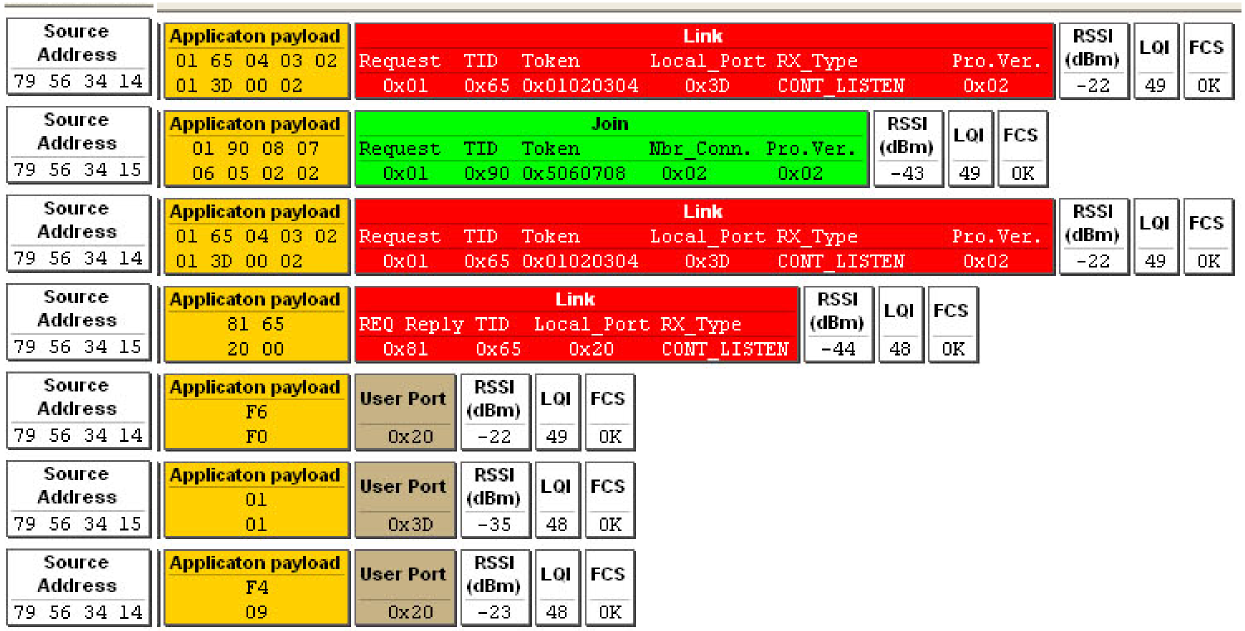

Figure 4. Network data packet verification using TI Smart RF Packet Sniffer.

Figure 4 is the screen display showing communication related data between two devices, #79 56 34 14 and 15. The figure is given to show the extensive nature of the details including information pertaining to where they Link, Join, Request, & Reply, payload data sent and received with the RF signal levels (-44 dbm and -22 dbm) seen at the packet sniffer (CC Debugger). More information about this feature is given in the Appendix. This verifies that the network and the client software on the devices are working. This report is a transmission between the systems shown in Figure 5.

Figure 5 is more than just verification that the display is working but first a discussion of what is taking place. The breadboard seen in the photo contains the prototype wiring for the I^2C connection between the Melexis MLX90614 sensor and the MSP430 CC1110 Mini DK board. The sensor is seen just to the left of the LED that is turned on. The sensor is reading the hand temperature of the student holding the ez430 Chronos watch. The CC1110 Mini DK board is to the right of the breadboard. It is talking to the sensor and passing data over the wireless peer to peer network to the eZ430 Chronos watch. The value displayed is low (30.7ºC is 87.26ºF). It should be noted that the sensor used in this setup has a FOV of 35º. This means the temperature of the student's hand is either cold or the ambient room temperature was included in the average temperature seen by the sensor. This is also an example of the need for the medical grade infrared sensor with an FOV of 5º. The information in Figure 5 verifies that the program on the CC1110 is working properly by requesting and passing data to the wireless network, and verifies that the program on the eZ430 Chronos is working properly by receiving the data from the wireless network then displaying it on the graphical display. The next phase involves working with a select group of subjects under simulated conditions with the sensors.

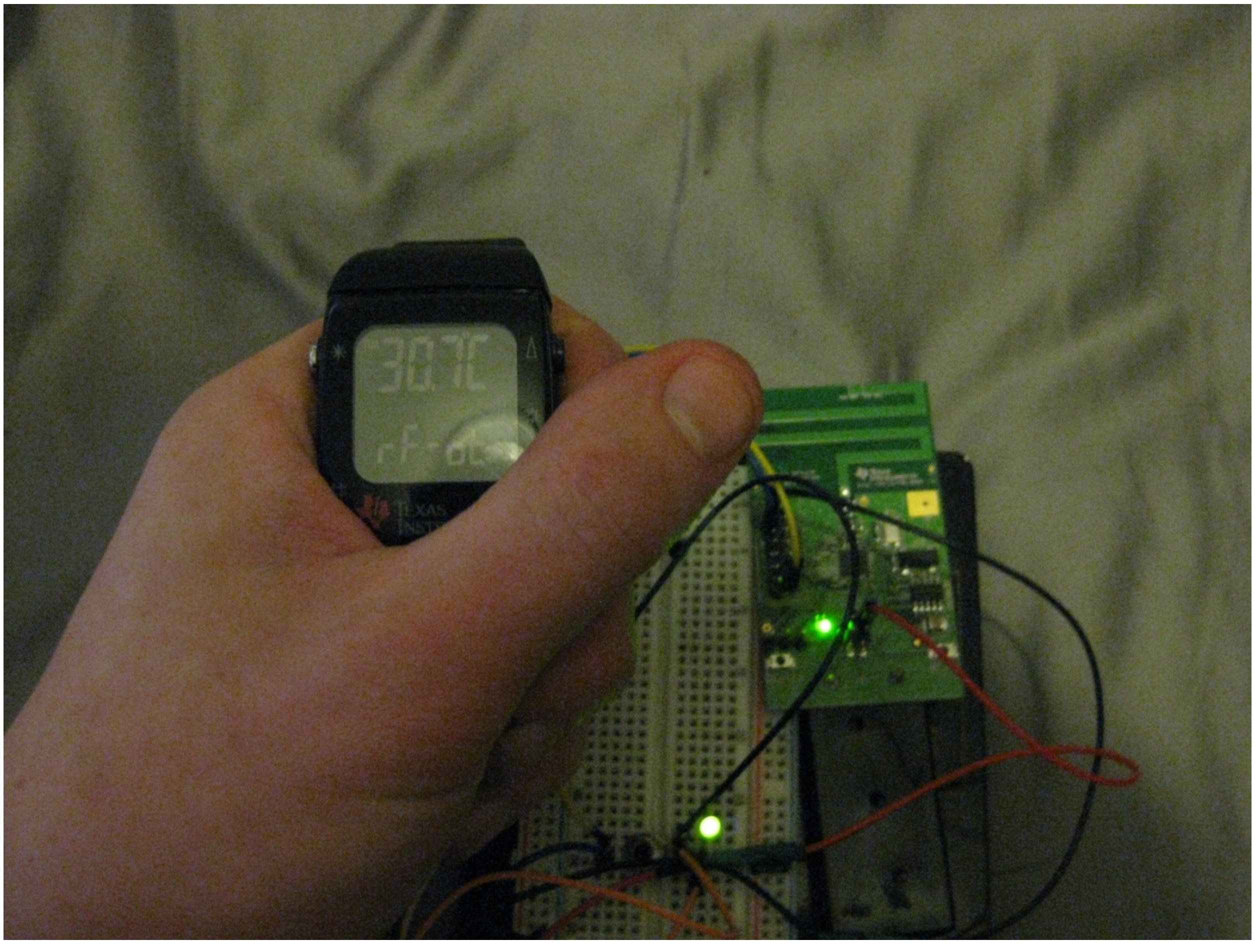

Figure 5. Photograph of the proposed screening system under test.

The temperature reading from the Melexis MLX90614 has been compared to a reference temperature sensor, EXTECH IR200 Non-Contact Forehead IR Thermometer for a previous paper.[3] The range of the star network was explored out to 50 yards without losing signal which covered the distances anticipated in classroom venues. Additional testing is planned using the CC Debugger so that specific decibel values can be obtained. Preliminary testing has validated the functionality of the stationary/portable screening system.

Discussion

The design of the system described is quite complex yet it is interesting in that the associated effort involve many different learning outcomes. In the pilot project, because of the difficulties an enthusiastic student was asked to participate outside of regular classes. He certainly had the skill set necessary for the anticipated challenges based on his prior work in this field. Due to his significant contributions, he is listed as the lead author for this paper and he played a key role as technical developer for the prototype design. Treating this design as a senior lab project, the following TAC-ABET outcomes can be considered:

(a) Apply knowledge of mathematics, science, and engineering.
(b) Design and conduct experiments and analyze and interpret data.
(c) Design a system…to meet desired needs within realistic constraints such as economic.

(d) Function on a multidisciplinary team.
(e) Identify, formulate, and solve engineering problems
(h) Understand the impact of engineering solutions in societal context.
(k) Ability to use the techniques, skills, and modern engineering tools for engineering practice.

It is very clear from the following observations that the set of TAC-ABET outcomes mentioned above blended very well with the project's outcomes. Each outcome achieved by the project is discussed in conjunction with the TAC-ABET outcomes in the following section.

(a) Knowledge of math, science, and engineering required by wireless sensing, field of view, temperature measurement, software programming, network design, and hardware selection was applied in the design.

(b) The student was able to design and test the system using knowledge he learned during the development, specifically the CC Debugger that came with the CC1110 Mini Development Kit. Experiments were designed using the CC Debugger for capturing packet information being sent between units proving the displayed information was due to communication between the sensor on the SmartRFCC1110 board and the eZ430 Chronos Watch Module. The analysis performed determined that the initial sensor used had too wide an FOV thus triggering an engineering modification of the system by changing to the medical grade MLX90616 infrared sensor with an FOV of 5º.

(c) In the project, the student designed the system interconnecting three different wireless microcontrollers with only general instructions from the faculty team members. The functioning system developed demonstrated the student's ability to design within realistic constraints.

(d) The project required working on a multidisciplinary team with faculty members from Electronics, Biomedical Engineering, and Industrial Design programs. The student was from Electromechanical Engineering and the multidisciplinary team members all contributed according to their specialty. The ability for the student to work in a multidisciplinary team was clearly demonstrated.

(e) An engineering problem was encountered during the project. The eZ430-RF2500 which was assumed to be the wireless link with the computer was operating on a different frequency from the eZ430 Chronos Watch Module used for the mobile display. The student identified appropriate hardware and software to solve the problem and still keep the same functionality of the design intact.

(h) The project selected was indeed one which has potentials for societal impact in terms of health care. In times of suspected pandemic situations, the solution proposed by the project certainly would raise the student's awareness to problems impacting society and the effect the project would have on healthcare.

(k) It is obvious the student used modern techniques and skills in this design because the system is completely wireless, all the devices selected were from the Texas Instruments MSP430 families all which were released after 2002. The Chronos Watch was released in 2010. The software used was IAR Code Composer's latest release.

Incorporating the learning aspects from this type of multidisciplinary project into the curriculum will in great part depend on the interests of the instructors teaching the appropriate courses. In the table below are listed various courses in the Electrical Engineering, Technology, and Biomedical Engineering curricula that could adopt techniques and devices from this project for use in updating and modernizing course instruction.

Table I. Possible applications of learning outcomes from the project in labs and courses at Wentworth Institute of Technology

Component/ Device	Course Number and Name	Course Outcomes
eZ430 Chronos Watch	Elec496 Advanced Sensors and Systems	Sensors used with microcontrollers
Wireless P2P Network CC1111 Mini Develop	Elec516 Computer Communication/Networks	Networks and network control
Wireless P2P Network CC1111 Mini Develop	Elec605 Senior Design	Demo project showing student competency in complex designs
Wireless network using SimpliciTI	BMED 660 Biomedical Systems Engineering	Design of complex systems in biomedical practice

It can be observed from Table I that the proposed design has great potential for adoption in numerous courses. Various institution and professors have adopted the TI eZ430-F2013 development tool as the default microprocessor to introduce students to the Texas Instrument MSP430 architecture. The hardware selected for implementing the system was based on cost and function to implement the system design objectives: low-cost, scalable, non-contact temperature screening. The low-cost objective was achieved by using the Texas Instrument MSP430 series of microcontroller. Economy of scale could keep the cost per unit below $100. The scalable objective was achieved by selecting wireless microcontrollers linked by a wireless network so that any system can expand from one to 128 units in larger venues such as lecture halls, symposiums, and sporting events. The non-contact objective was achieved by selecting a medical-grade infrared sensor. Based on the results obtained from the present project, it is intended to continue the design development for both the stationary and mobile modes of wireless sensor network involving multiple sensors and perform additional testing on a larger student cluster.

Conclusion

The proposed system shows the feasibility of a design that incorporates low-cost, scalable, and non-contact fever screening. From an educational standpoint, this system is a demonstration that the project facilitates achieving several of the TAC-ABET student outcomes. Extending the present project to larger sets of students could lead to positive results with multi-disciplinary project-based learning.

Acknowledgement
The authors wish to thank the support given by Henry C. Lord Chair Fellowship and Wentworth Institute of Technology, Boston, MA. The authors also appreciate the donation of the temperature sensors by Melexis Microelectronic Systems, Belgium, for use in the design and development of the prototype.

Appendix
The eZ430-Chronos 915 MHz wireless development kit from Texas Instruments (TI) was selected for the monitoring and user interface portion of the design. The basic hardware of the eZ430-Chronos kit includes a customizable wireless watch, eZ430-Chronos watch, a wireless access point (AP) with a USB interface, CC1111 USB RF AP, and a USB debugging interface for the watch, eZ430 USB emulator.

Figure 6. eZ430 Chronos Wireless Development Tool.

The eZ430-Chronos watch features a TI CC430F6137 micro chip unit (MCU) combined with a 96-Segment LCD, five buttons, a buzzer, a 3-axis accelerometer, an ambient pressure sensor, an internal temperature sensor, and a battery voltage sensor. The CC430F6137 MCU is version of the TI CC430 family of *(1) ultra-low power system on chips (SoCs), and contains an integrated MSP430 microprocessor and wireless CC1101 > 1GHz (868 MHz to 915 MHz) RF transceiver radio. The watch includes an antenna design that uses the metal frame that surrounds the LCD of the watch module for RF communication.

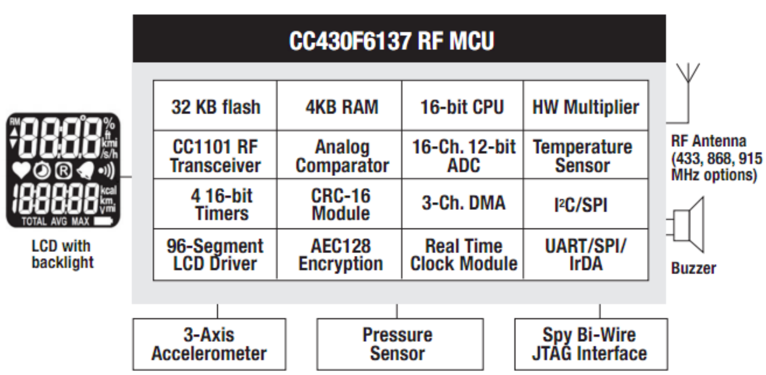

Figure 7. eZ430 Chronos Watch microcontroller block diagram

Figure 4-8. eZ430-Chronos Watch Module Front

Figure 8. eZ430 Chronos Watch Module Display function controls

The CC1111 USB RF AP is mainly comprised of a *(2) low power CC1111F32 MCU that is a SOC integrated with a 8051 microprocessor, a > 1GHz (868 MHz to 915 MHz) RF transceiver radio, and a full speed USB controller. The AP also includes a chip antenna for RF communication.

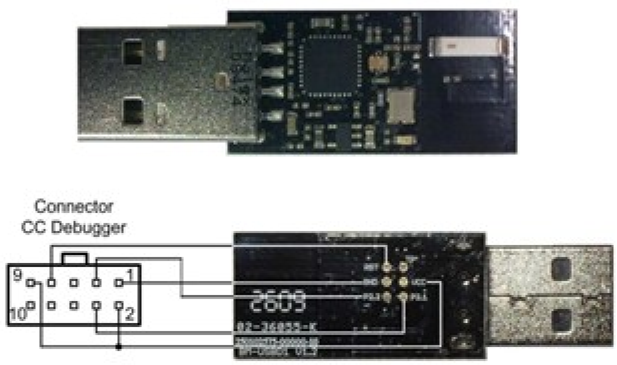

Figure 9. eZ430 CC1111 USB RF AP.

The USB debugging emulator that comes as part of the eZ430-Chronos kit allows for programming and debugging the watch's CC430F6137 over a Spy-Bi-Wire. Since the AP uses a very different MCU than the watch, an additional programming and debugging interface, a CC Debugger, is required in order to modify the default firmware of the AP. As well, a header must be soldered on the AP before programming and debugging can be accomplished.

The hardware selected for the sensor node design is the TI CC1110 Mini DK wireless development kit. The CC1110 Mini DK includes two SmartRFCC1110 target boards and a CC Debugger for programming and debugging the target boards.

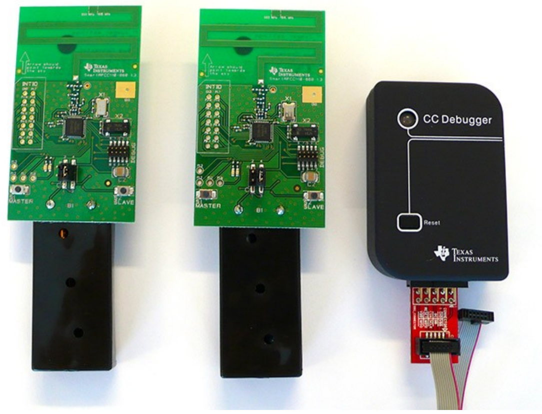

Figure 10. CC1110 Mini DK Wireless Development tool.

The SmartRFCC1110 target boards are designed for evaluating the CC1110F32 MCU, and the main difference between the AP's CC1111F32 MCU and the CC1110F32 is that the CC1110F32 lacks a USB controller. Additional features on both target boards include two LEDs, two buttons, and a PCB based antenna for RF communication. One purpose for the CC Debugger is to program and debug the SmartRFCC1110 target boards. An additional benefit of obtaining the CC Debugger for this project was that it could be used for programming the AP's CC1111F32 MCU.

Figure 11. MLX90614 Infrared sensor in a TO-39 container.

The MLX90614DCI is an infrared sensor for non-contact temperature measurements. The thermometer comes factory calibrated with a digital PWM and SMBus (System Management Bus) output. The MLX90614 is built from 2 chips developed by Melexis:

1. The Infra Red thermopile detector MLX81101
2. The ASIC (application specific integrated circuit) MLX90302.

The calculated object and ambient temperatures are available in RAM of the MLX90302. The resolution is adjustable down to 0.01 °C. They are accessible by 2 wire serial SMBus compatible protocol (0.02°C resolution) or via 10-bit PWM (Pulse Width Modulated) output of the device. The MLX90614 is factory calibrated in wide temperature ranges: -40…125 °C for the ambient temperature and -70…382.19 °C for the object temperature.

The science behind temperature measurement

An infrared sensor uses the heat radiated from the object to determine the temperature. The temperature of a human body is a function of the average kinetic energy of the molecules[1] that dissipate as phonons.[7] Phonons have two properties, acoustical and optical with the acoustical wave being a longitudinal wave while the optical wave being one or more transverse waves.[8] The Einstein's formula predicting the heat capacity per mole at constant volume is:

$$C_v = 3kN\left(\frac{hv}{kT}\right)^2 \frac{e^{hv/kT}}{\left(e^{hv/kT}-1\right)^2}$$

What this says is the heat energy is directly related to the frequency of the vibrations of the optical photons (in the equation *v* represents frequency).[9] The intensity of the frequency of the energy is what is being measured when a temperature is read by non-contact means. The frequency of the transverse wave emitted is in the infrared spectrum and varies between .7 micron and 20 microns for common objects.[10]

The portion of the infrared energy that passes through an object is the emissivity of the object.[10] A blackbody is a theoretical material that emits all its infrared energy. A blackbody has an emissivity of 1.[11,12] A human subject is not made of a homogenous material and therefore emits infrared energy at different intensities for a given temperature.[10] One characteristic of humans is their surface is not smooth thus permitting a higher level of emissivity. In order for an infrared transducer to correctly measure the temperature the emissivity of the subject must be known. Fortunately this is a known value. Humans subject have an emissivity of .97.[12,13] Emissivity must be taken into account to compute the temperature accurately when using infrared devices. During the initialization of the sensor, this value must be written the sensor's memory so that it can be use to convert the observed temperature correctly.[4]

An infrared sensor is made up of a number of thermocouples called a thermopile. A thermocouple converts heat into current by physically coupling two dissimilar metals together such as copper or constantan and nickel or iron. In an integrated circuit layers of different material from which a current will flow constitute the thermopile.[14] Thermopiles are considered emf devices similar to a battery except they are sensitive to radiated heat.[15]

The conversion of the reading from the thermopile and the emissivity into temperature is by Stefan's Law:

$$P_{rad} = \sigma e A T^4$$

In this formula sigma, σ, is the Stefan-Boltzmann constant, $5.6704 \cdot 10^{-8} W/m^2 \cdot K^4$, *e* is the emissivity, A is the area of the thermopile in the sensor, and T is the temperature in kelvins which is the unknown value we seek. P_{rad} is the amount of energy per unit of time corresponding to the energy transfer to the thermopile.[15] The thermopile energy can be converted to a wattage (the W seen in the formula) by the measuring the current flow over time through a resistance. By using an adaption of Stefan's formula to calculate the net transfer and using a calibrated thermopile internal to the sensor to determine the ambient temperature the difference between the object being read and the ambient temperature is determine and thereby the actual temperature of the object.[4]

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