

Design and Development of a Non-Contact Thermography Device for Equine Research

Dr. Faruk Yildiz, Sam Houston State University

Faruk Yildiz is currently an Associate Professor of Engineering Technology at Sam Houston State University. His primary teaching areas are in Electronics, Computer Aided Design (CAD), and Alternative Energy Systems. Research interests include: low power energy harvesting systems, renewable energy technologies and education.

Ms. Haley Claire Collins

Dr. Jessica L. Leatherwood, Sam Houston State University

Dr. Marcy Miller Beverly, Sam Houston State University

Dr. Marcy Beverly is currently a Professor in Animal Science in the Department of Agricultural Sciences and Engineering Technology at Sam Houston State University (SHSU). She holds B.S. in Agricultural Economics and Ph.D. in Animal Science from Texas A&M University and M.S. in Agricultural Business from Sam Houston State University. Marcy was raised in Huntsville, Texas and her passion for agriculture was sparked through father at a young age. Growing up in the 4H realms, she has maintained her participation through serving as superintendent for a state livestock show and county committees. Marcy serves as the advisor to the Block & Bridle Club and coordinates many of the community service efforts for the department. For the past 15 years at SHSU, she has focused her efforts in teaching, scholarly and service not only for the university and professional avenues but for the community.

Dr. Mark J. Anderson, Sam Houston State University

Mark J. Anderson is and Animal Science professor at Sam Houston State University whose research focuses on how alterations to the management and breeding of live animals will affect the biology of muscle and meat tissue.

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Abstract

Equine events such as racing, rodeos, fairs, breed association sanctioned shows result in a congregation of animals, and there is a high risk for the spread of disease among participating horses. This risk can be lowered through an effective biosecurity program. An important part of a biosecurity program is to have a rapid method used to obtain reliable body temperature measurements because changes in body temperature are often a vital indicator of infectious animal disease. Fever refers to a consistent rise in body temperature that is more than a normal range (99.5 to 101.0°F) and is one of the most commonly recorded clinical parameters in the physical examination of a horse. Measuring body temperature in animals includes the use of rectal thermometers and thermal microchips. These temperature measurement methods have different limitations such as intolerance to the procedure, time required to obtain the measurements, or the need to have a microchip implanted in each animal and a portable scanner that can read the microchip. Taking these limitations into a consideration, a team of students (Animal Science, Engineering Technology, Electronics, Electronics and Computer Engineering Technology (ECET), and Industrial Design & Development) and faculty were challenged to design and develop a low-cost non-contact infrared thermography device. This was a special and interdisciplinary project (not a capstone project) that was proposed by Animal Science faculty. Students and faculty in the project team designed and built the device after investigating existing similar products in the market.

Introduction

Fever is a common indicator of infectious disease in animals. However, collection of a rectal temperature can be difficult and stressful on the animal. New technologies such as thermal imaging cameras have recently become more prevalent to collect the body temperature of animals at other, less invasive sites. The objective of this research was to compare a first generation prototype non-contact thermography device (NCTD) to a traditional FLIR® thermal imager as well as to determine a comparison between rectal and thermographic temperatures as an indicator of health status [1].

A traditional clinical or serological examination of large numbers of livestock is logistically and economically challenging, and visual observations alone are not the most sensitive indicators to detect early disease. A potential method for measuring temperature that does not have these limitations is noncontact infrared thermography because it is passive, the results are rapid in the hands of trained personnel, and it entails a noninvasive procedure. The use of infrared thermography as a non-invasive method for fever and stress detection in animals holds great promise; however, limitations to the use of infrared thermography include both the availability and cost of the equine devices to the consumer. In addition, as previous literature suggests further in baseline and controlled studies with the ability to determine infrared repeatability and accuracy of infrared thermography are required. In humans, noncontact infrared thermometers are available for taking body temperatures; modifying these instruments for equine applications would be beneficial to the usability, application, and efficacy for the equine industry.

Infrared thermography has a long and convoluted history, with its application having been tested through many different facets. Initially, William Herschel, a physicist from the 17th century, designed an experiment in which he measured the temperatures of each color of the spectrum using sunlight and a glass prism. He found that while the temperature of color increased from violet to red, temperatures continued to increase past the red light, indicating the presence of light and heat that are invisible to the human eye. He subsequently coined the term “infrared” meaning “after red” which initiated the use of thermal detection through this discovery of new light [2].

This discovery would not prove useful until well after Herschel’s time, but has since become important in human medicine as well as military use. Devices were developed that are able to capture these invisible lights and convert them to thermal images. In the 1950s, the US Air Force partnered with Texas Instruments to develop a thermographic line scanner for the purposes of detecting people and other living or moving objects at night or through smoke and smog. Additionally, infrared thermography (IRT) was used by the military for diagnoses of problematic machinery and equipment. Almost concurrently with these developments, IRT was being adapted for use in human medicine for the detection of certain cancers. Lawson (1956) found there were significant differences in the surface temperatures of cancerous tissues when compared to non-cancerous tissues [3]. Additionally, it was discovered that IRT was able to detect peripheral vascularity of cancerous tissues on other extremities. This development facilitated further research into the efficacy of thermal imaging, and today it is widely recognized as a diagnostic tool for breast and various other cancers where peripheral vascularity is observed and can be detected below the surface of the skin.

Today, the use of thermal imaging has diverse applications and is highly used in medicine and health. In the field of animal science, this technology has been applied to differentiate stress susceptibility in pigs of various genotypes [4-5]. The study recorded a range of temperatures from 16-34°C for both sides and dorsal measurements and found that overall, when scanned with an IRT device, pigs with lower side temperatures had a higher percent drip loss and paler colored meat, often resulting in a less than desirable quality product. The report also noted that highest temperatures in most cases were found to be at the ears. These animals were observed in groups in order to determine the potential stressors encountered by each animal. The investigators found that regardless of their genotype, when introduced to certain physiological stressors such as transportation and restraint, groups of pigs was more likely to produce lower quality carcasses. The lower surface temperatures could be due to the stress inflicted on the animal causing the blood to move away from the surface and toward the muscle. The study proposes IRT as a useful means of detecting those pigs likely to produce lower quality carcasses prior to slaughter. The device used for this particular study was an Agema model (782).

Another related study was comparing rabbit rectal thermometry with 4 other thermometry techniques such as an implantable microchip temperature transponder, an environmental noncontact infrared thermometer, a tympanic infrared thermometer designed for use on humans, and a tympanic infrared thermometer designed for use on animals. In this study a microchip transponder was implanted between the shoulder blades; the environmental noncontact infrared thermometer recorded results from the base of the right pinna and the left inner thigh, and the tympanic infrared thermometer temperatures were taken from the right ear of a rabbit. The

outcome from each technique were compared to determine agreement between the test modality and the rectal temperature. The practicality and reliability of the modalities were reviewed also. The summary of this study was the implantable microchip transponder measurements agreed most closely with the rectal temperatures [6].

Currently, the industry standard for determining body temperature involves the use of a rectal thermometer. Unfortunately, this method may be a safety risk for handlers and unfavorable to the animal. While the use of a rectal thermometer is widely regarded as the most effective industry practice, more modern methods are being developed and tested including IRT devices. Benefits of this technology include rapid temperature detection and a lack of invasiveness. IRT is a technology that detects infrared energy on the surface of an object, produces a temperature reading, and depending on the specific device, includes an image displaying temperature distribution. While this technology has the advantage of being non-invasive, since it does not require contact with the subject being measured, it is limited to reading only surface temperatures. Even so, it has shown potential for the ability to detect rises in body temperature, although additional evidence is needed to show its effectiveness in this matter.

The use of thermography as a non-invasive method for fever and stress detection in animals holds great promise; however, limitations to the use of thermography include both the availability and cost of the equine devices to the consumer. In addition, as previous literature would suggest, there needs to be an improvement in the baseline and controlled studies to determine repeatability and accuracy of thermography. In humans, noncontact thermometers are available for taking body temperatures. Modifying these instruments for equine applications would be beneficial for usability, application, and efficacy with the equine industry.

There are three phases in this project. In this paper, only Phase I of the project is discussed. The second and third phases of the project are either in the process or will be considered for future presentation. Phase I of the project is development of a hand-held non-contact thermography device. All the steps of this project are shown in Figure 1.

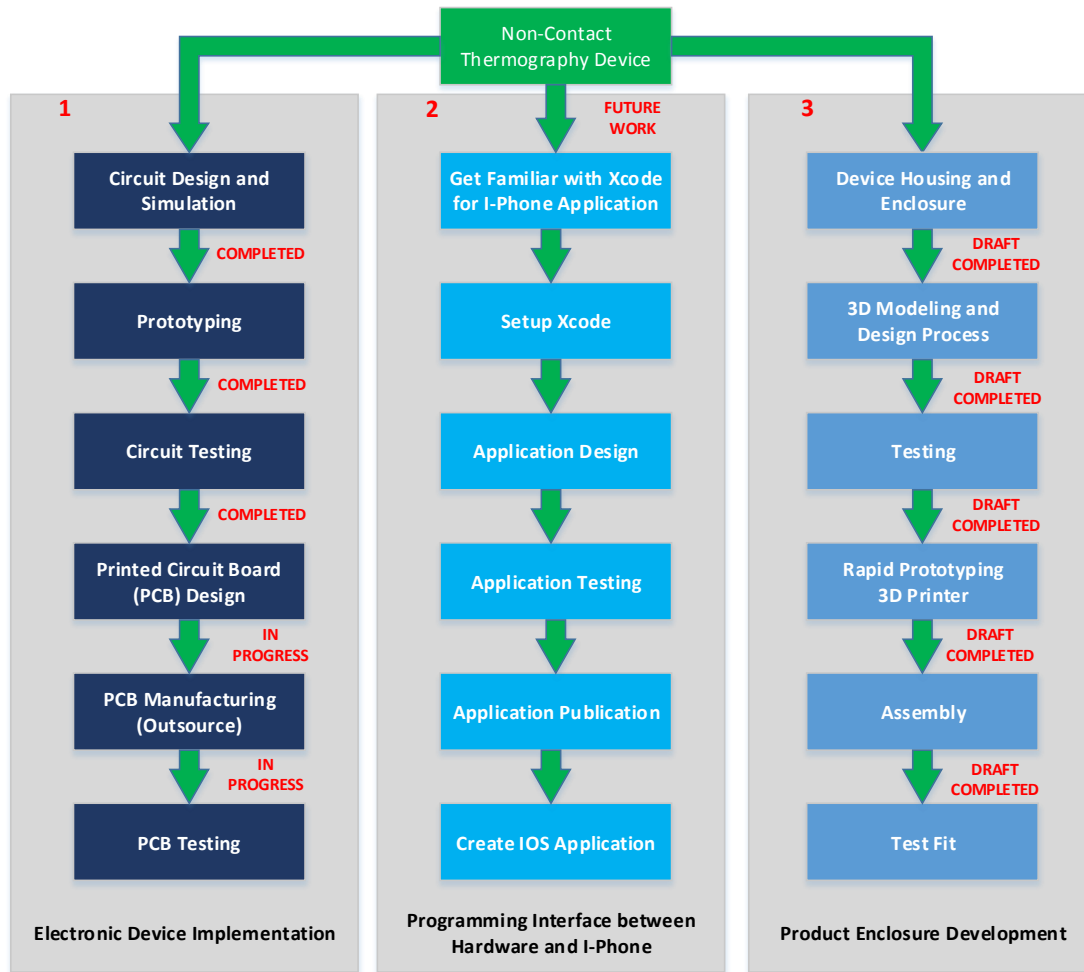


Figure 1. Design and development steps of the complete product.

Figure 1 shows the diagram of the design and development steps of the complete product. The implementation of some of the steps in the diagram was postponed due to the graduation of two student-majors working on the project. For example, the smart phone application preparation (middle column) is considered as a future work. These steps will be implemented as a future work; there are two students from the ECET program are currently interested in working on the incomplete steps of the project.

Circuit Design

The project team initially investigated existing similar products in the market to determine functionalities of the similar products. For the circuit design and development, an initial step was building the complete circuit by implementing the microcontroller development board on a prototyping board (breadboard). There are four main modules on the breadboard. The first one is the Arduino microcontroller development board [7], second is the LCD display [8], the third module is the Real Time Clock breakout board kit [9], and the fourth one is the MicroSD card [10]. The photos of the complete prototype circuit and testing are shown in Figure 2.

The circuit was tested several times by the animal science students, and improvements were made based on the comments made from animal science students and faculty.

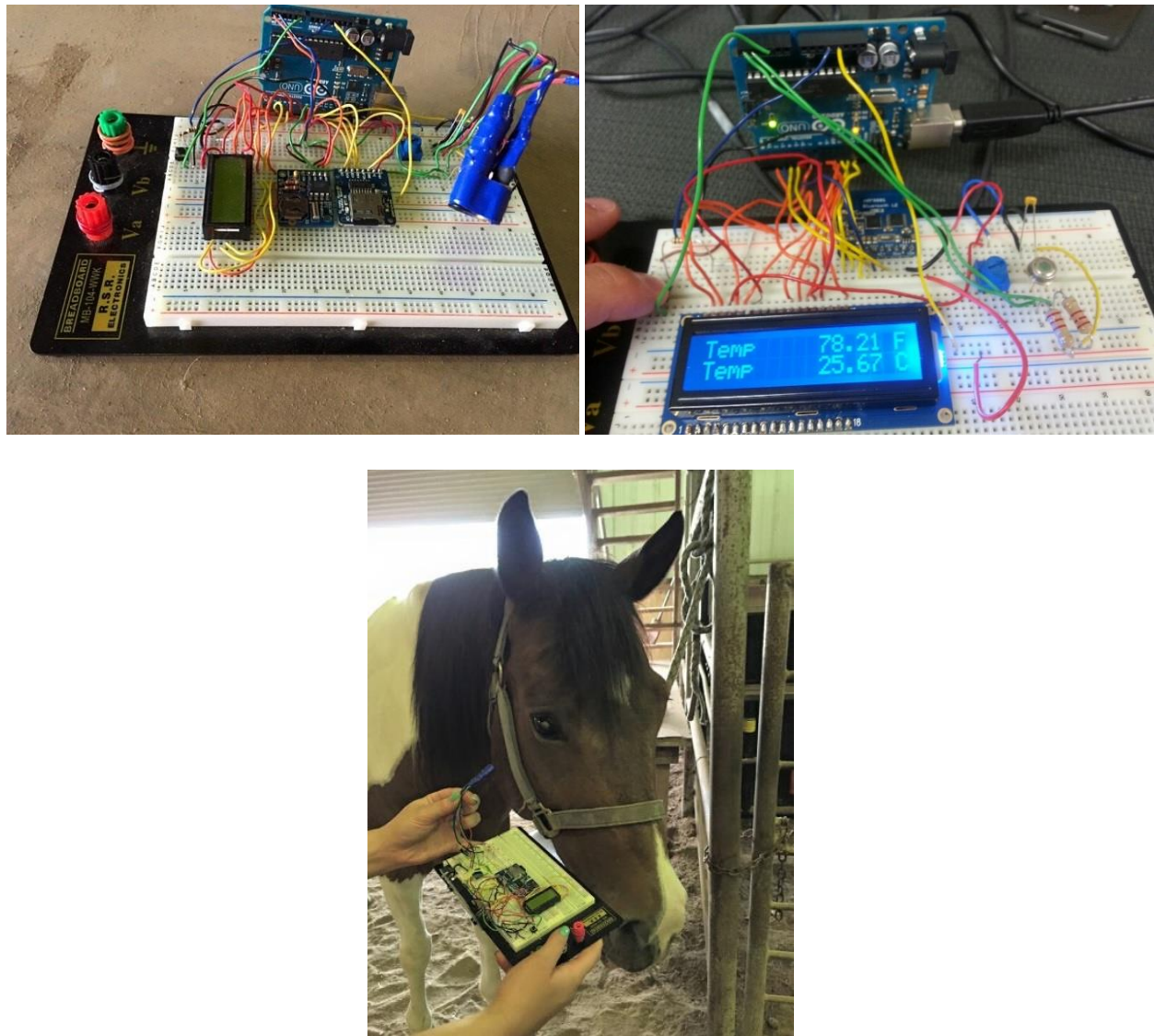


Figure 2. The Prototype Non-Contact Thermography Device (NCTD) development board testing

For the microcontroller and programming platforms, students were offered several microcontroller development boards/kits with different microcontroller architectures that are available in the electronics lab. Table 1 shows a list of potential development boards that are available in the laboratory for the project. After investigations of capability, use, and ease of learning of the each systems, students decided to use an Arduino UNO development board [7]. The programming environment for the Arduino board is similar to C programming. One of the students had a C course and decided to program on a Arduino board. Another student was a computer science graduate student who advised ECET undergraduate students on an as needed basis.

Table 1. Potential Microcontroller Development Boards

Embedded Systems Development Board/Kit	Version/Type	Manufacturer/Company
Arduino - UNO	AVR Arduino UNO Rev 3	Arduino
ARM	Cortex	Texas Instruments
Raspberry Pi 2	Model B - ARMv7	Raspberry Pi Foundation
MSP430 Launchpad	MSP-EXP430G2	Texas Instruments
Basic Stamp	2.0	Parallax
PIC / DSPIC PICDEM Lab Dev Kit	PIC / DSPIC	Microchip Technology

Two types of infrared sensors used for this project. First one was, MLX90614 infrared thermometer from Melexis technologies [11]. The MLX90614 is an Infra-Red thermometer for non-contact temperature measurements. Both the IR sensitive thermopile detector chip and the signal conditioning ASIC are integrated in the same TO-39 can. Integrated into the MLX90614 are a low noise amplifier, 17-bit ADC and powerful DSP unit thus achieving high accuracy and resolution of the thermometer. The thermometer comes factory calibrated with a digital SMBus output giving full access to the measured temperature in the complete temperature range(s) with a resolution of 0.02°C. The user can configure the digital output to be PWM. As a standard, the 10-bit PWM is configured to continuously transmit the measured temperature in range of -20°C to 120°C, with an output resolution of 0.14°C. When NCTD measurements were compared to high end FLIR camera, the temperature differences were different. Therefore, the project team decided to use another infrared temperature sensor to determine if the measurements were different because of the first infrared temperature sensor or circuit design. The second infrared temperature sensor that was implemented was MLX90615 Infra-Red Thermometer [12]. The temperature measurements were compared again. With the new temperature sensor, the difference were minimum. Another request from the animal science students and faculty was to implement a laser pointer to make sure the temperature reading is taken from specific points. A laser pointer was implemented and installed with temperature sensor at a specific angle.

The schematic of NCTD is shown in Appendix A. This schematic was prepared for use by the animal science student during the testing process. Initially, a complaint was made by the animal science students who conducted the testing using the breadboard to get temperatures of the horses. Some of the wires became loose in the breadboard socket, and students did not know how to re-connect the wires. The schematic is used to show wiring of the device prototyped on the breadboard. This schematic can also be used by the students who will continue on this project after the graduation of the current students who started this project.

3D Model and Prototyping

For the product enclosure/housing, a student majoring in industrial design and development worked on a design using Autodesk Inventor. The design goal was to work on a housing for the complete device with a printed circuit board (PCB). However, the enclosure design was only for the prototyping circuit housing the Arduino development board, sensors, electronics components, memory card etc. After design completion, a 3D printer was used for the prototype enclosure.

Several design changes were applied to fit the modules and components properly in the housing. The photos of enclosures with the modules installed are shown in Figure 3.

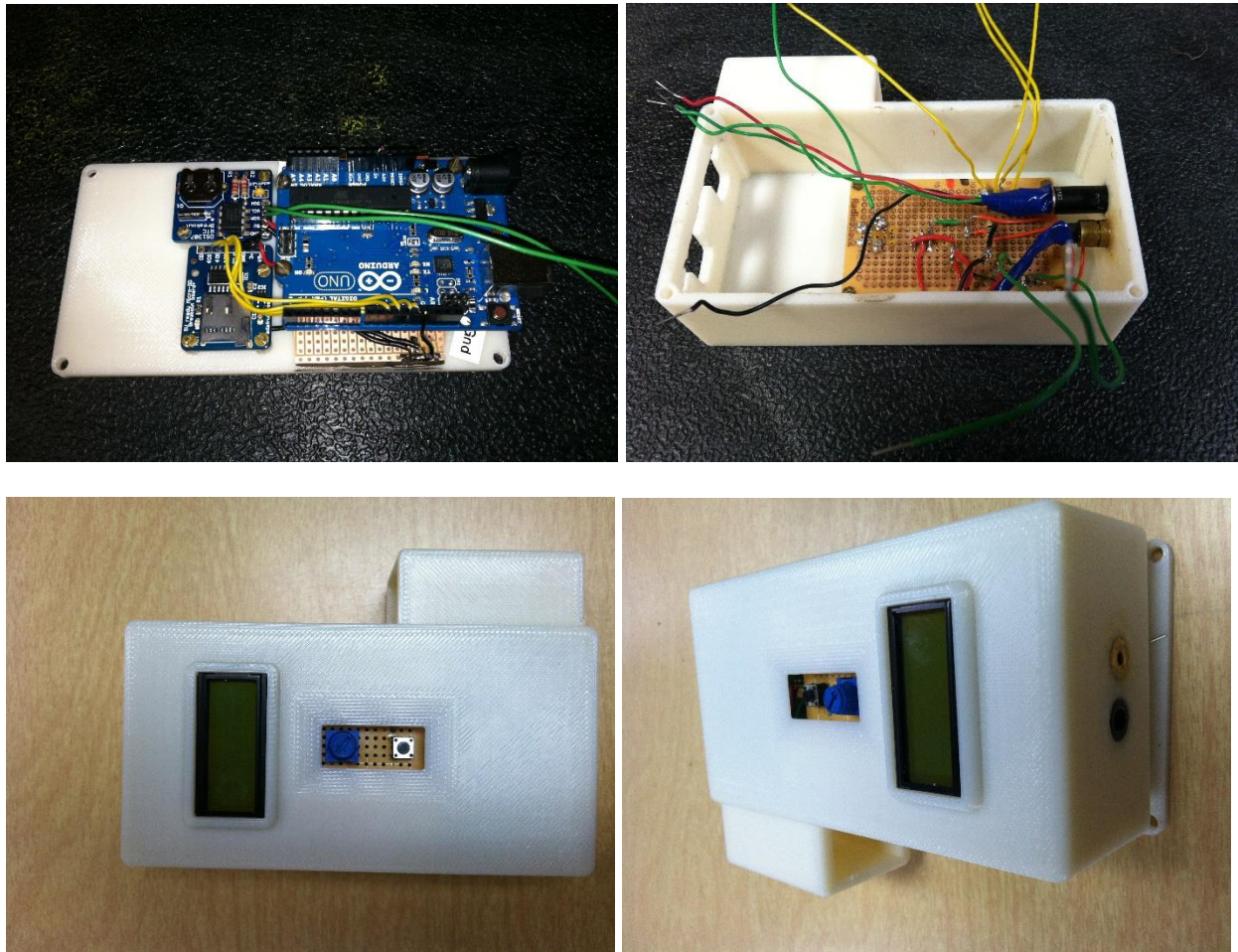


Figure 3. NCTD Enclosure 3D Printer Prototypes

Testing and Measurement Phases

The device was tested in 3-phases by animal science graduate students. All 3-phases are summarize below.

Phase I

Phase I evaluated the efficacy of the first generation prototype NCTD in its first field testing in order to validate its use against a traditional FLIR® thermal imager and determine both devices correlation with rectal temperature. The focus of the first phase centered on the eye of the horse, specifically focusing on the three following areas: medial canthus (MC), ocular globe (OG), and lateral canthus (LC). Each area of the eye that was measured is illustrated in Figure 4.

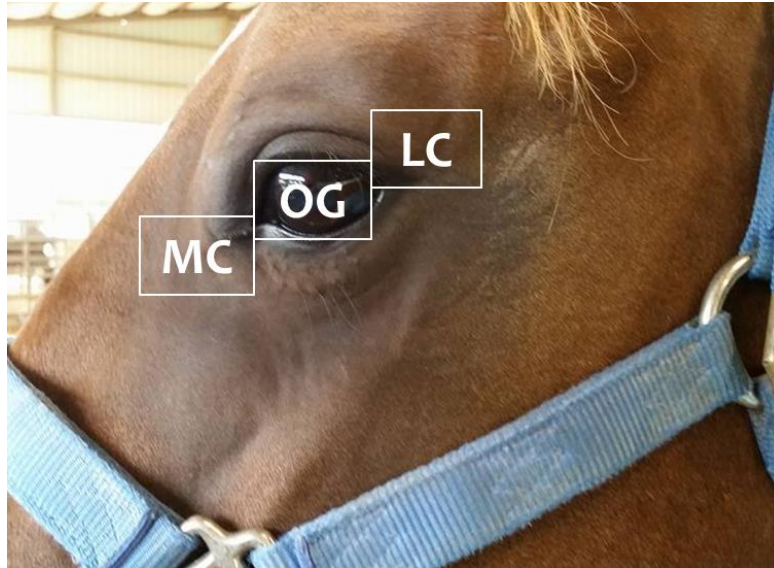


Figure 4. Illustrates each sector of the eye (MC; Medial Canthus, OG; Ocular Globe, LC; Lateral Canthus) that was measured using a FLIR® E60 Thermal Imaging camera (FLIR® Systems Inc., Austin, TX) and a new Non-Contact Thermography Device.

Measurements were taken by both the FLIR® and NCTD at a 1 m distance of each location on the eye. Rectal temperatures were also collected to serve as the standard to which we determined body temperature. Measurements were taken on 20 sedentary horses (2-9 yr; 357 to 540 kg) over 5 days for a total of 100 measurements. Each measurement was taken within a singular covered stall barn, with each horse measured within their own stall. This allowed for a great amount of uniformity between measurements as the location remained constant. Additionally, relative humidity and ambient temperatures were recorded in order to evaluate the impact of environmental effects on the devices. Relationships between measurements were determined using the PROC CORR procedure of SAS.

Phase II

Modifications were made to the NCTD prior to the start of the second phase as a result of issues discovered during Phase I. The angle of the sensor was narrowed to 5 degrees and a red laser pointer was added to assist with a more accurate aim. Additionally, the device was programmed to produce an average value along with the individual values previously utilized. The average is produced using every 5 values collected, which allowed for a more consistent evaluation of temperature in a specific location. Following the improvements made to the device measurements were taken using both the FLIR® and NCTD at a 1 m distance from each location of the eye (MC, OG, and LC). Rectal temperatures were also recorded to serve as the standard measurement of body temperature. From this secondary round of data further evaluation of the device to the established FLIR® model was assessed, as well as to further observe the ocular temperatures relationship to rectal temperature. For this phase, 91 measurements were taken on sedentary horses (2-15 yr; 357 to 540 kg). There were notable differences however, in the setting of which these measurements were taken. In the beginning of Phase II, 20 measurements were taken within a single stall barn, while the remaining 71 measurements were taken at a similar

event facility in West Monroe, Louisiana over the course of two days. This created greater variability in terms of light and air exposure, time of day, and other various environmental factors. Relative humidity and ambient temperature were recorded at the time of each measurement in order to determine if these factors affected the thermal measurements. As in Phase I, relationships between measurements were determined using the PROC CORR procedure of SAS.

Phase III

The purpose of the third phase was to test the NCTD and FLIR® at additional locations on the horse in order to compare them back to rectal temperature. Additional areas of the horse were selected based on accessibility, a relative lack of fat coverage, and possible presence of viable superficial veins that may allow for better thermal expression. The following locations were measured on each horse: eye, muzzle, lower lip, throatlatch, forehead, back of the ear, bridge of nose (side), front face of the knee, front leg cannon bone (side), where the neck and chest meet, girth, hock, flank, and tail head. All measurements were taken using both the FLIR® and NCTD from a 1 m distance as previously utilized. Rectal temperatures were also collected through this phase of the trial. For Phase III, 100 measurements were taken at each location on sedentary horses (2-15 yr; 357 to 540 kg). The location in which horses were measured remained constant throughout this phase of the data collection; horses were kept in an unenclosed but covered facility when measurements were taken. However, environmental variables did exist, and it should be noted that the facility was unenclosed and horses received variable sun exposure when compared to others. Furthermore, this phase required a greater number of measurements to be taken per day. Therefore, more time elapsed from the beginning to the end of the measurements. This allowed for changes in natural lighting, ambient temperature, relative humidity, presence of wind, etc. Relative humidity and ambient temperatures were recorded for each horse at the time each of their individual measurements was taken. For this phase, data were analyzed using the PROC CORR procedure of SAS to determine the relationship between measurements and the PROC REG procedure of SAS to determine the relationship between rectal temperature and temperatures at multiple locations on the body.

Discussions

The enhancements made to the NCTD device following the first phase showed improvements in performance throughout the second phase after adding a new infrared sensor. The simple addition of the laser pointer allowed for a much more accurate aim to the specific area being measured. However, use of the laser pointer would have been moot if not for the angle of the camera being narrowed. By reducing the scope of the sensor from 45 degrees to 5 degrees, it allowed for further accuracy when targeting a specific area of the horse and therefore added confidence in values recorded. It should also be noted that the new NCTD device is still in development and continues to encounter minor errors when in use. Because the device remained on the development board throughout testing, the components of the device were always exposed and susceptible to alterations.

Multiple instances of the device failing to work occurred during this early testing phase, which caused delays in data collection. These delays allowed for environmental changes to occur such

as a rises in ambient temperature and drops in humidity as the day progressed. It is possible that the changes that occurred in the environment caused variation among the data which may have create inconsistencies in results. Still, the novel device shows potential to measure thermographic temperatures; the device functions similarly to a FLIR® Thermal Imager but is a fraction of the cost to produce. Once the device is encased; further tests will need to be performed to show if additional stability will allow for more consistent results.

The statistical analysis of the measurements suggest the improvements made following Phase I may have allowed for enhanced relationships between temperature detection methods; however some issues concerning variability still exist. The results of measurements using both NCTD and the commercial FLIR® camera show that the relationship between the FLIR® and the new NCTD device decreased slightly following Phase II but remain relatively consistent overall. However, the results of the second phase show a closer relationship between rectal temperatures and the reading from NCTD device, increasing from $r=0.37$ ($P \leq 0.05$) to $r=0.41$ ($P \leq 0.05$) at the Ocular Globe and $r=0.18$ ($P \leq 0.05$) to $r=0.28$ ($P \leq 0.05$) at the Lateral Canthus (r : linear relationship – correlation coefficient; P : significance). The improved relationships could very well be the product of the updated device, however the improved correlations are not substantial, and other factors should be considered when discussing differences in the data.

Student Learning

Students involved in this project conducted structured independent research, used creative thinking, and shared hands-on experiences that also were beneficial to their gained knowledge. Students can obtain valuable knowledge by doing research related to their major/minor. There were five undergraduate and two graduate students involved in this project. Two of the students were majoring in engineering technology – electronics, one was majoring in engineering product design, and one was measuring in electronics and computer engineering technology. Additionally, two animal science graduate students were part of this project by testing the device and giving feedback to undergraduate students for device improvements. One of the graduate students used this project as her graduate thesis project. Two of the undergraduate students were graduated and offered jobs at local companies. The hands-on experience from the project provided the students with the opportunity to demonstrate the knowledge that they have gained in major courses. Students learned about various aspects of embedded systems (microcontrollers), electronics, engineering product design, prototyping including problem identification, technical, social and environmental constraints, multidisciplinary team management, communications, and documentation skills. Through practice, the students realized that the key success for a design project is team work, industry interaction, and collaboration.

Summary

In terms of the development of the NCTD, additional phases will need to be executed to determine its true potential for temperature detection in a production setting. The results of Phase III suggest there are additional sites on the horse, aside from the eye area, that may allow for more consistent readings between the NCTD and the FLIR®. Furthermore, because the eye temperatures remain relatively consistent among the results of each phase, this location could still be optimal for temperature detection. The additional sites where the correlations between

devices were found to be strong may not be ideal in terms of accessibility in a production setting. Locations such as the chest, knee, cannon bone, girth, flank, hock, and tail head could possibly complicate the process and may prove to be less convenient than eye temperatures. The non-invasive nature of these thermography devices should alleviate some of these complications, and these additional areas should not be ruled out without further investigation.

While this study serves to reveal the utility of varying thermography devices to detect body temperature, it also exposes the additional work needed to further validate their effectiveness. The results of this study show the NCTD and the FLIR® to operate similarly at not only the eye, but also multiple other sites on the horse. This new knowledge allows for additional possibilities of us, and confirms the novel device's state as viable for use in infrared thermal temperature detection. However, the new NCTD device is in need of encasement and perhaps further enhancements to solidify its accuracy in the way of an established model such as the FLIR®. There have been improvements in the device thus far, and it shows great potential as a valuable tool that is efficient and accessible within the equine industry. Currently, it seems the device may best serve its purpose as a preliminary screening tool to determine the potential for an animal harboring illness. In this case, a maximum temperature must be established, at which point animals meeting or exceeding this point would be removed for further evaluation. Utilization of this technology has the potential to greatly reduce risk for spread of diseases, and allow for a healthier and better maintained population of horses within the industry.

Future Work

The second step shown in Figure 1 and some of the sub-steps (in progress) under steps 1 and 3 will be completed as future work. The major accomplishment will be communication between the device and a smart phone by adding a smart phone application. The application will report the equine issues to the user based on the temperature readings. The application will automatically generate reports when the temperature readings are downloaded to any external device. For the programming interface, Xcode software for IOS applications will be used (one seat) to create a smart phone application to report implications based on temperature reading. All the software and hardware are available in the department facilities. An Xcode software and some of the electronics devices will be purchased. The final non-contact thermography device will have a USB connection to download temperature readings to a smart phone for reporting to the user. The application will report the equine issues to the user based on the temperature readings. The application will automatically generate reports when the temperature readings are downloaded to the device.

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Appendix A: NCTD diagram

