

EXTERNAL THERMAL CAMERA EXPOSURE CONTROL WORKAROUND FOR LOW-COST SECURITY THERMAL CAMERAS

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Abstract

Thermal cameras have an advantage in feature extraction, namely the ability to show only objects with/according to temperature; for example, a person with a higher temperature than the immediate surroundings could be extracted from the background with simple machine vision techniques. The problem with industrial thermal cameras for security use is that they are very expensive. A solution would be to obtain less expensive security thermal cameras. However, a problem inherent to these cameras is their automatic self-calibration system. This is problematic in fixed constant comparator programs.

This paper proposes a calibration system to regulate the optimal exposure parameter for the analysis of a single, possibly under- or over-exposed image. This calibration system provides an optimal exposure reference for the camera, based on image clarity and reduced image noise. The phenomenon of image noise is caused by under- or over-exposed images. To estimate the exposure quality in the presence of saturated and unsaturated pixels, a temperature-controlled surface is introduced into the camera's field of view. The camera's calibrating point is aimed at this surface; therefore, this is a reference temperature for the camera. Experimental results are presented comparing different reference temperatures to target visibility. The experiment was conducted in a controlled environment.

Keywords: camera, calibration, machine vision, thermal imaging, exposure control.

1. INTRODUCTION

Thermal cameras have an advantage in feature extraction of objects of temperature. The problem in relation to security, is that industrial thermal cameras are expensive compared to security thermal cameras. In addition, security thermal cameras have an inherent problem as part of their required function in that they have an automatic self-calibration system. Correct image exposure is crucial for virtually any machine vision application. The loss in perceptual image quality is noticeable when under- or over-exposure occurs; texture or features are also decreased. Correct exposure means that the desired object in the image is clear and background image noise is reduced to a minimum.



In view of proposals regarding reference calibration temperature along with software to regulate the surface temperature to correct under- or over-exposure, this article is structured as follows: The literature review presents a discussion of key concepts and hardware selections. This is succeeded by an explanation of the methodology regarding the experiment and then its findings and discussion. The conclusion summarises the proposals and indicates future directions.

2. LITERATURE REVIEW

To design an external thermal camera exposure control workaround for automatic self-calibration low-cost security thermal cameras, one needs to define and evaluate the concepts and hardware options in the following five subsections.

2.1 Thermal imaging camera

The start-up cost for a vision system using thermal imaging will be higher than that of a standard camera, but thermal cameras offer greater visibility and flexibility when tracking objects that produce heat. This makes it a more viable option when heat-based object identification is required.

Thermal cameras operate within the infrared region. Infrared light radiation involves a longer wavelength than visible radiation does, as seen in Figure 1. Infrared radiation is a less penetrating type of radiation, and therefore a special detector is required. There are two methods of using infrared light to enhance vision capabilities in low-light situations. The first is active infrared that sends out a beam of infrared light and gathers the reflected waves. The second is passive infrared that collects infrared radiation from surrounding objects and amplifies it to form a picture. Thermal imaging is capable of capturing long-wavelength infrared (LWIR) thermal radiation; this allows for the visual representation of infrared radiation.

Thermal cameras observe the absolute temperature of an object. This observation is in the mid-infrared radiation in the infrared spectrum. Thermal cameras use thermal radiation, mainly heat-generated from surrounding objects. Standard infrared cameras can detect humans clearly in the dark and are therefore perfectly suited to identifying people. These cameras are capable of detecting in the 7 μm – 14 μm infrared spectrum – as is explained by Vollmer (2011) and shown in Figure 1.

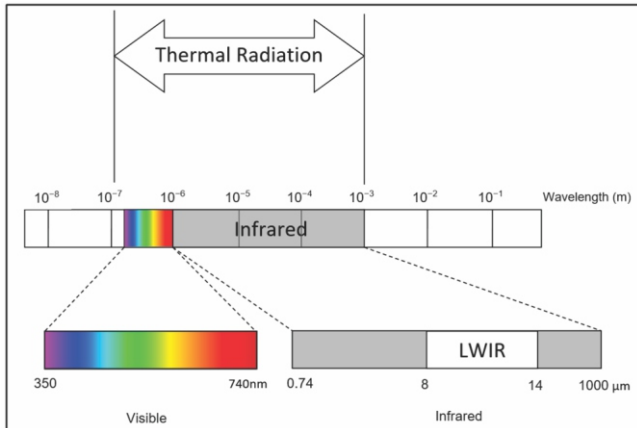


Figure 1: Thermal radiation spectrum

Different infrared cameras use different detectors to detect infrared light. The thermal camera utilised in this experiment is an Axis Q1921 uncooled microbolometer camera; it is self-cooled and does not require any additional cooling. Previous high-resolution thermal sensors required extreme cooling methods which restricted their use to that of stationary cameras. The microbolometer is a type of bolometer that is used in detecting infrared radiation with wavelengths between 7.5 and 14 μ m (Thomas, 2009:4). Infrared radiation strikes the detector material and heats it, thus changing its electrical resistance. Such changes are measured and processed into temperatures that are used to form an image. The Q1921 has a noise equivalent temperature difference (NETD) of 100 mK. The NETD is referred to as the camera's thermal contrast and occurs when the noise is equivalent to the smallest measurable temperature difference, and the detector has reached the limit of its ability to resolve a useful thermal signal.

2.2 Arduino

An external thermal camera exposure control needs a microcontroller. An Arduino UNO microcontroller is an inexpensive tool used to interface software with hardware. It uses an ATmega328P microcontroller and features digital and analogue I/O pins with pulse width modulation capabilities. The Arduino is also capable of running a standalone application or functioning as a data acquisition unit.

2.3 Temperature sensor

An external thermal camera exposure control needs a reference temperature sensor for control. The MCP 9700E sensors are linear active thermistors, which are analogue temperature sensors that convert temperature to analogue voltage. Linear active thermistors do not require an additional signal

conditioning circuit, which means that the sensor's voltage output pin can be directly connected to the analogue pin of a microcontroller. The MCP9700E is immune to the effect of parasitic capacitance and can drive large capacitive loads. This allows the sensors to be extended and placed away from the microcontroller.

2.4 Temperature control

Heating of the external thermal camera exposure surface was achieved by overdriving a resistor. The 12 ohm resistor was used as such a heating element on demand from the Arduino. It is capable of producing 2.08 watts of power, as is calculated in Equation 1. Surrounding the resistor is a housing made of aluminium, which dissipates heat and keeps the temperature constant.

$$\begin{aligned}
 \text{Power} &= \frac{\text{Voltage}^2}{\text{Resistance}} \\
 P &= \frac{(5V)^2}{12\Omega} \\
 P &= 2.083W
 \end{aligned}
 \tag{1}$$

2.5 LabVIEW

LabVIEW is a programming language like any other, except that the code is graphical. Its compiler directly translates the graphical code into machine code where the run-time engine (RTE) executes it. LabVIEW does not communicate directly with the hardware that needs to be controlled or monitored. Instead, it goes through an application programming interface (API). LabVIEW interacts with hardware drivers that do the lower-level work and interact with Data Acquisition (DAQ) hardware using DAQmx drivers. LabVIEW comes with an Arduino toolkit so that input-output peripherals can be controlled (Stamps, 2012:6).

3. METHODOLOGY

Figure 2 shows the layout of the experiment and placement of the components. The calibration surface is visible inside of the camera's field of view.

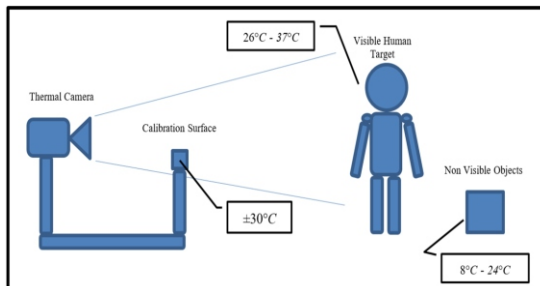


Figure 2: Thermal camera calibration system layout

Figure 2 captures the proposed solution for an external thermal camera exposure control workaround for self-calibrating low-cost security thermal cameras. The following sections show the construction and evaluation method for this solution.

3.1 Hardware setup

Figure 3 is a constructed solution of Figure 2. The experiment setup indicates the camera on the left pointing to a person on the right, close to the camera. The calibration surface is visible in the camera's field of view. The camera is slightly angled to allow the calibration surface to be visible in the area of view without obstructing the target. The Arduino is connected to the computer using a universal serial bus (USB) cable. The computer then runs software that monitors the voltages on both the thermal sensors. Based on the temperatures that the sensors are reading, the resistor is switched on until the desired temperature is achieved. The computer runs LabVIEW, which is used to convert the voltages received from the sensors to degrees Celsius and then to decide when to switch the resistor on or off.

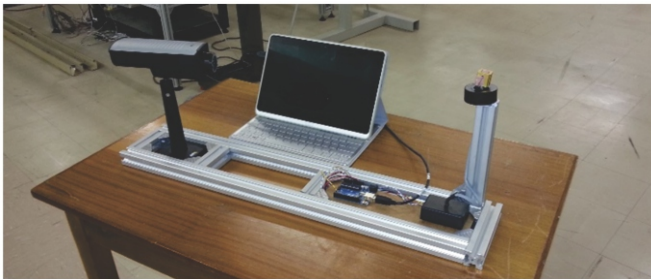


Figure 3: Experiment setup used to capture participant

Figure 4 shows the thermistors and resistor inside the aluminium case connected to the Arduino. The right hand side shows the calibration surface in thermal vision. The thermistors are connected to the Arduino's analogue pins, and voltages are read from them. The voltages from the thermistors are converted to degrees Celsius and used to monitor the temperature of the calibration surface. One thermistor is mounted close to the heating resistor and the other on the outside of the calibration surface. This allows accurate temperature monitoring. The analogue to digital conversion (ADC) is done using a program that reads the analogue value from the temperature sensors. The temperature sensors data sheet with conversion information enables one to convert the analogue values to degrees Celsius.

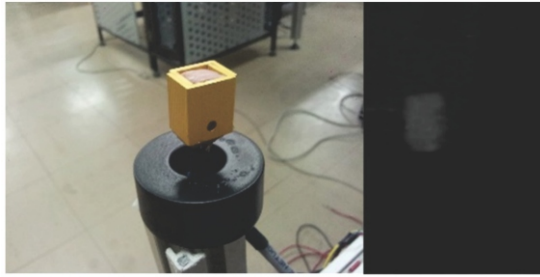


Figure 4: Calibration surface construction

Equation 2 takes the analogue input and converts it to voltage. The maximal voltage of the Arduino can measure equals 5 V, and the A/D converter's resolution is 10 bits, which means 1024 values. The sensor has a 500mV value at 0°C and a temperature coefficient of 10 mV / °C.

$$Temperature = \frac{\left[AnalogueRead(0) \times \left(\frac{5}{1024.0} \right) \right] - 0.5}{0.01} \quad (2)$$

The Arduino also switches on the heating resistor in the calibration surface. The desired temperature is selected, and the resistor is switched on or off depending on the temperature read from the two thermistors.

3.2 Software setup

Figure 5 illustrates the logical flow followed to achieve the desired output in the program. The purpose of this LabVIEW program is to establish communication with the Arduino Uno and then use the Arduino platform to read and write values to sensors and electronics connected to the Arduino. Communication to the Arduino is achieved using the USB. This means LabVIEW uses a virtual COM port to communicate with the hardware via USB.

Once the Arduino is plugged in, the COM port number which it occupies becomes visible in the Windows Operating System. This COM port number can be specified in the program to establish communication. Next, a connection has to be initialised to the Arduino Uno. This specifies the baud rate, board type, bytes per packet and connection type. These parameters change with different kinds of Arduino boards.

This VI also opens the serial connection port; it then sends a sync packet to the Arduino and waits for a response that is an identical sync packet. Once communication is established, the Arduino's analogue and digital pins can be controlled. Before entering the main loop of the program, the digital pin responsible for switching the heating resistor has to be specified as output. The main loop of the program manages three functions:

- Analogue voltages from the two thermal probes are read.
- These voltages are converted to degrees Celsius and put through a smoothing filter.
- The thermal resistor is switched on at the correct time to heat the calibration surface (no PID calculation is done; only value averaging).

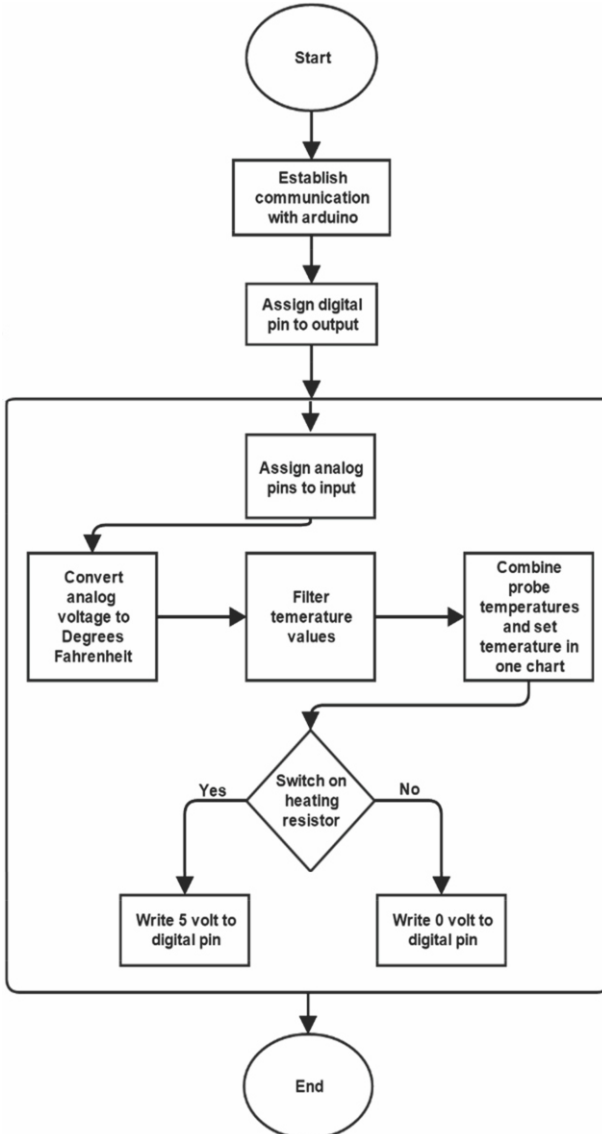


Figure 5: Flow process of the calibration software used together with thermal imaging camera.

Figure 6 shows the front end of the software that controls the set temperature for the calibration surface. Two temperatures can be seen in the figure; these are used to form an average temperature value. A software filter acts as a time-delayed feedback control to stabilise the average temperature, and this causes a delayed average temperature reading. The temperature values from the probes are also filtered to stabilise the readings.



Figure 6: Software used to control calibration surface temperature

Camera software

A built-in feature of the camera's software (called exposure settings) allows the user to specify a static point on the image; the built-in camera software uses that point to calibrate its exposure. This calibration point can be small, and the reference position can be adjusted in the camera's software. An external device capable of heat regulation had to be placed in front of the camera to allow calibration of the exposure and to keep the exposure constant

3.3 Experiment

In the experiment, data relating to how different temperatures on the calibration surface influence image clarity and background noise were gathered. A person was recorded at the four-meter mark at five different exposure settings that were regulated with the calibration surface and measured in temperature. The temperature started at 25 °C and was incremented by 2°C until it reached 35°C. This means that six photos had to be analysed to determine what temperature would work best for background noise reduction. Lights, computer monitors, computers and any object radiating heat were removed from the camera's field of view.

2. FINDINGS AND DISCUSSION

Figure 7 shows how the camera reacts to different calibration temperatures in the case study. The calibration surface is used to adjust the exposure of the camera. The auto-exposure function is trained to react only to the calibration temperature. The most effective temperature ratio between subject temperature and ambient temperature needs to be established to decide whether the calibration surface is working.

The first image in Figure 7 shows that ambient temperature is noticeable if the calibration surface is at 25°C. Any object other than the human subject is classified as background noise and needs to be eliminated or reduced. Normal human body temperature will range from 37°C down to 20°C. This is because the average human body temperature has a maximum of 37°C (Heymsfield, 2005:168) and the skin and clothes seen by the thermal camera are influenced by external factors like ambient temperature.

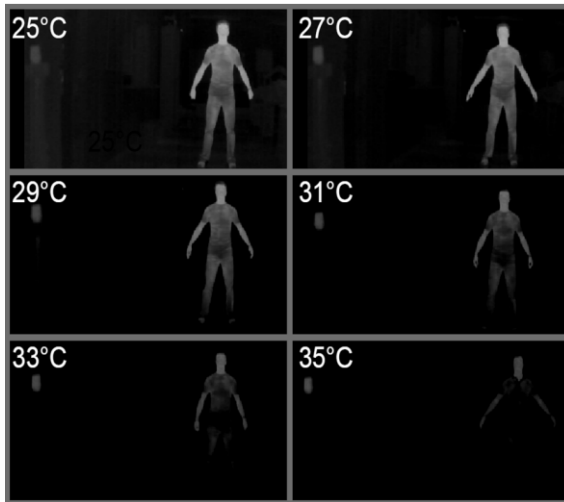


Figure 7: Image of how the camera reacts to different temperatures on the calibration point

The calibration surface allows one to eliminate some of the background noise by raising the surface temperature. If the desired temperature spectrum is between 27°C and 37°C, the calibration surface will be adjusted to 26°C. This enables one to cut out all temperatures below 26°C and observe only temperatures higher than 26°C. All objects with a temperature higher than the calibration set temperature will be visible. Unfortunately, undesirable objects that are warmer than the calibration surface will also be visible. Post-image processing could be used to eliminate objects that are warmer than a human being is.

Figure 8 is a graph comparing visible area (that is, the infrared radiation emitted by a human body) and calibration surface temperature. Plotted on the chart is the target area or object of interest and the amount of background noise. The target area is measured via particle analyses using LabVIEW software.

Figure 8 reveals the balance that must be maintained when adjusting the camera's exposure manually. When the temperature on the calibration surface is increased, background noise is reduced substantially. Also, note that visibility on the human target decreases, but much more gradually. The optimal temperature for the calibration surface was found to be slightly below 29°C. Background noise was almost eliminated and enough detail and visibility remained on the human target. The optimal temperature was selected based on the largest amount of visible particles that remained on the target and the least amount of background noise.

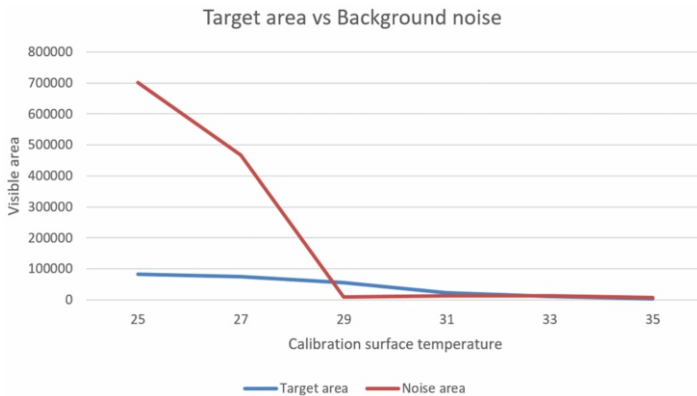


Figure 8: Human area vs. background noise visibility

Figure 8 represents the analysis of six photos taken with the thermal imaging camera. Each photo was taken at a different exposure value that was set using the external calibration device. Figure 8 shows how an increase in temperature decreases background noise and also the target area. To improve image clarity, background noise needs to be reduced, yet still allow a large enough target area to be visible.

The results show that changing the exposure on the camera can decrease background noise significantly. This involves heating the calibration surface from 25°C to 35°C. The results furthermore show that increasing the heat will shorten the exposure of the camera and reduce the visibility of a human subject, as seen in Figure 7 and Figure 8. An increase in calibration temperature reduces background noise as well. Reducing the heat on the calibration surface will increase subject visibility and also background noise.

5. CONCLUSION

Although thermal imaging cameras are becoming more affordable, they are still relatively expensive. Some key features might be removed or image quality reduced to make the cameras less expensive. With the Axis Q series thermal imaging camera, no manual exposure adjustment was present. Overcoming this problem required the use of the reference exposure function that is built into the camera. This also required the use of an external heating surface that acted as a calibration surface for the exposure of the camera.

In terms of the results, adjusting the exposure can significantly decrease background noise for a thermal imaging camera. The software presented also allows for easy adjustment of exposure. A limitation might be surface emissivity of IR systems. Note that the surface emissivity of the calibrator remains constant so that it can render repeatable results. Human beings emit heat, but if the object under investigation does not emanate heat or is of a different material, then inaccuracies in absolute thermal measurement may occur.

The problem presented and solved in this article is very specific to a particular camera. Thermal imaging cameras are expensive and therefore using these particular cost-effective cameras was essential. Future research includes the development of software capable of detecting a human being in the field of view of the camera. Once a human being is detected, the software should be capable of tracking that specific person. Object-based tracking can be greatly improved by the reduction of noise and non-essential detail in an image. It was essential to obtain the best possible image from the camera before beginning image processing.

This paper proposes a reference calibration temperature along with software to regulate the surface temperature to correct under- or over-exposure. An external calibration system (rather than the camera's default auto-exposure function) is used to increase the practical industrial application of a simple security camera. For example, vision systems mounted on mobile robots need to identify a human being in order to improve human-robot interaction. The proposed solution is an optimal reference calibration temperature that will produce minimum background noise and a surface large enough to allow a means of tracking the human target.

6. REFERENCES

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