Surface moisture detection using thermal imaging and computer vision

Raveen Appuhamy[a], Yuandi Wu[b], Faraz Alderson[c], and S. Andrew Gadsden[d]

[a]Department of Mechanical Engineering, McMaster University, Hamilton, Ontario, Canada

ABSTRACT

Thermal imaging is used to detect moisture inside surfaces such as walls or floors by showing the temperature difference between the moisture and the structure. Surface moisture detection can be critical in quality assurance, healthcare, construction and agriculture. This paper aims to extend the usage of thermal imaging and computer vision to detect the coverage of moisture on the surface using computer vision rather than relying on an end user. This process relies on the thermal properties of the liquid that is sprayed on a surface, which would have a distinct temperature difference compared to the surface it is on. The methodology proposed in this paper is to utilize an infrared thermal image camera to analyze the surface. Then, using computer vision, the output is processed to detect the areas of the largest temperature gradients while filtering the noise. This ensures only areas with a large enough gradient are highlighted, capturing the sprayed surface. These areas are converted to a percentage of the captured area and displayed to the user. Preliminary findings from the experiments show that the system is able to detect liquids that have a temperature difference of at least 5 deg C (9 deg F). As this method only relies on thermal imaging, it is a non-destructive and non-invasive test, where the user does not need to interact with the surface or the liquid directly. The information provided by the technology can contribute to fault detection and quality control when it comes to spray coverage.

Keywords: thermal imaging, surface moisture detection, computer vision, infrared applications, thermal imaging applications

1. INTRODUCTION

Thermal imaging is the process of capturing the infrared radiation emitted by an object. Thermal cameras use infrared thermal sensors which are made from thermophiles. Thermophiles convert thermal energy to electrical energy, which is then read to generate data. The data can then be presented using pictures and videos, where the thermal camera outputs an image using colour to represent temperature, typically associating cooler colours with cooler temperatures and warmer colours with warmer temperatures 1. Thermal imaging can be used in a variety of industries as the infrared information can be obtained non-destructively for construction, food quality and fault detection.

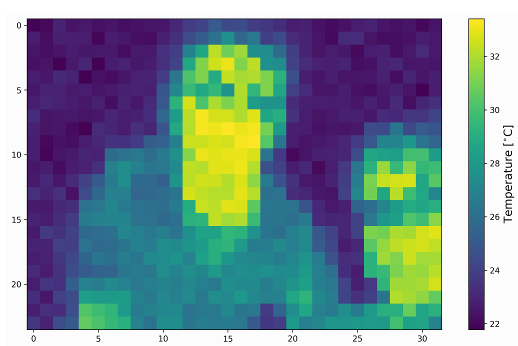

Figure 1. Example of a thermal plot

Further author information: (Send correspondence to Raveen Appuhamy)
Raveen Appuhamy: E-mail: appuhamr@mcmaster.ca, Telephone: 1 (905) 525 9140 ext. 21121

Thermosense: Thermal Infrared Applications XLVI, edited by Fernando López, Nicolas P. Avdelidis, Giovanni Ferrarini, Proc. of SPIE Vol. 13047, 130470G · © 2024 SPIE · 0277-786X · doi: 10.1117/12.3013954

There have been multiple avenues that research using thermal imaging has taken. Infrared thermography can be used to investigate the condition of buildings. Barbieri et al. use it to observe the internal and external behaviour of brick masonry after wetting.[1] The thermal images snapshot the water transport properties of the walls. Using the FLIR P620, they were able to test untreated walls as well as the use of two hydrophobic coatings. The results of the thermal images demonstrated that the coatings slowed the drying of the internal moisture. Similar research was conducted on concrete buildings, where using similar tools, they were able to map the moisture pattern as well as the thermal characteristics in the wall without the direct measurement of temperatures.[2]

In the food production sector, thermal imaging can be used to grade rough rice. Grading rice is a quality assurance method used by the rice industry. Current approaches to grading use filter, edge, detection, and machine vision. As moisture content is an important characteristic to quantify, thermal imaging can be used to measure the moisture of a sample. This method proved to be 97.3% accurate at detecting the moisture content and 95.04% accurate at detecting foreign matter. This process can be an additional method as a non-contact, non-destructive method to classify the quality of the rough rice.[3] Thermal imaging has also been used to identify and classify the quality of mangos. The bruised area of mangoes emits greater heat than the regular area, and by taking thermal images of these bruised and unbruised mangoes, a convolutional neural network was applied to differentiate normal and defective mangos achieving a classification accuracy of 99.6%.[4]

Thermal imaging has also been researched for fault detection. Cable terminal faults can be observed by obtaining thermal data from the surface of the power cable terminal. When a large temperature change is detected and it is greater than the fault threshold, then a detection result is sent to the user.[5] On a smaller scale, a similar test was completed by measuring the temperature of computer components in different environments with various thresholds to see how applicable thermal imaging would be. It was found that fault detection of electrical systems can be completed using thermal imaging after calibration is completed for the operating location.[6] Thermal imaging fault detection has also been applied to piping. By taking thermal images of the pipe, steam pipe leaks, missing insulation or a broken outer layer can be detected.[7]

This paper proposes a method of using a thermal imaging camera to detect the percentage of moisture in an area. This can be used in manufacturing, processing and healthcare industries.

2. METHODOLOGY

This paper uses a thermal imaging camera to detect a spray area on a surface. This can be used in a disinfecting or manufacturing process to see if proper coverage is obtained. The tools used for the experiment are a Raspberry Pi 4b and the MLX90640 Thermal Camera. The MLX90640 Thermal Camera Breakout Board from PIMORONI has an FOV of 110 deg. The MLX90640 has an array of 768 thermal sensors and can detect temperatures within a range of -40 to 300 deg C. The sensor is connected to the Raspberry Pi via the GPIO pins. The camera sends the temperature read by each sensor in an array. A Python script, using Matplotlib is then used to convert the array into a thermal image. Ideally, these images are then fed into an OpenCV script to analyze the colour gradients and identify the areas of interest. OpenCV is a popular open-source Python library that is used for real-time computer vision and image processing. However, running the thermal camera is resource-intensive on the Raspberry Pi so instead of using a live feed from the camera, a collection of images was taken by analyzed by OpenCV in a separate script.

An overview of the methodology is as follows. The MLX9040 is connected to the Raspberry Pi 4b. Then thermal images of the spray patterns are taken using the thermal camera. Then using OpenCV, the thermal images are analyzed to see how much of the spray can be observed. A surface is then sprayed with water at varying temperatures and the thermal images are captured.

For this paper, the following processes are discussed.

1. Developing workflow to gather images from the thermal camera
2. Using OpenCV to analyze the thermal images and measure the area based on temperature differences
3. Conducting tests on sprayed areas to verify effectiveness

3. EXPERIMENT

To collect images from the MLX90640, Figure 2 shows the wiring diagram to connect the Raspberry Pi to the thermal sensor. Using the MLX90640 library and Python, the images of the spray were collected. Each thermal sensor outputs the temperature, where the raw data is in a 32x24 array. Matplotlib is used to convert that array into a colour map which can be used as a heat map. A temperature bar is included to give context to what the colours in the heat map represent. An example image from the camera can be seen in Figure 3, where the blue area represents a colder area.

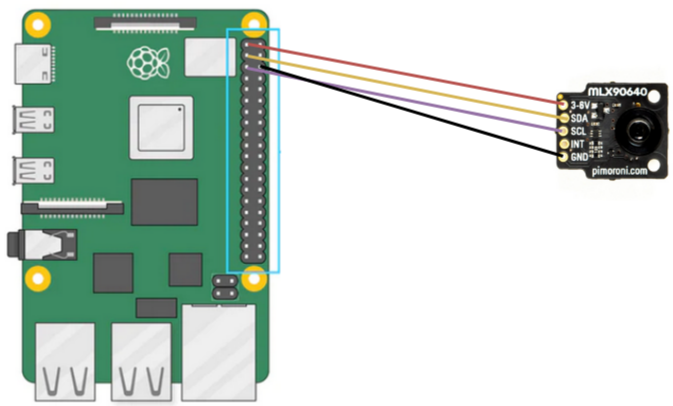

Figure 2. Wiring Diagram for the Raspberry Pi to the MLX90640

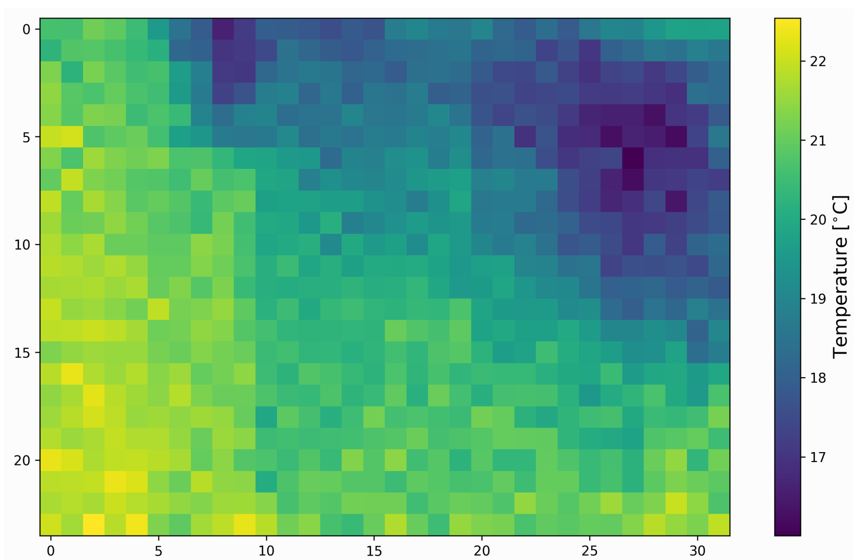

Figure 3. An example of the thermal image from MLX90640

Once the thermal camera images were taken, a second script was used to analyze the images using OpenCV. The images were imported, and then the script looked for the target colour range of a specific temperature range. Then this area is highlighted and the percentage of coverage is calculated based on the percentage of pixels highlighted versus the total number of pixels. An example of a highlighted heat map is shown in Figure 4.

A surface was sprayed and then thermal images of the surfaces were collected. First, water was sprayed at room temperature. Then the water was cooled in a refrigerator for 15 minutes to about 15 deg C. This

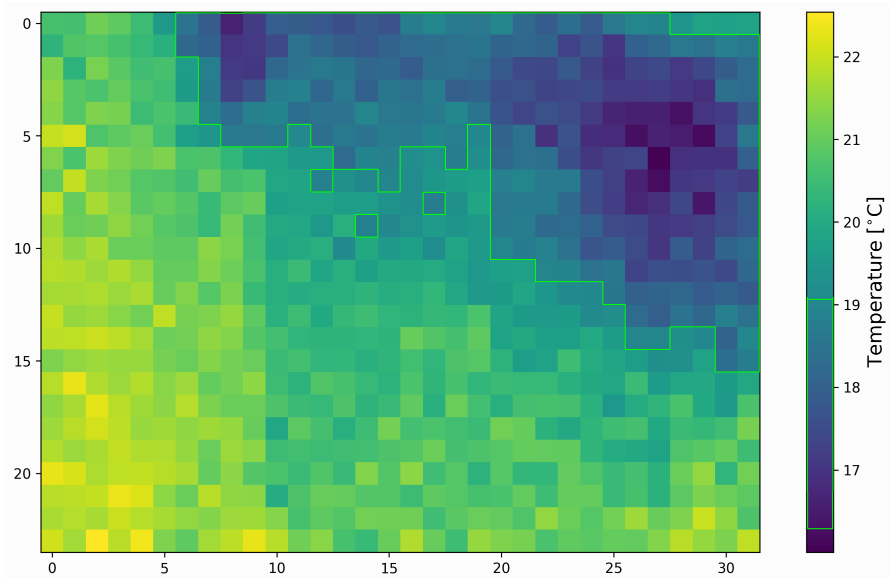

Figure 4. An example of the highlighted thermal image using OpenCV

temperature was selected to see what minimum temperature difference required to capture a temperature gradient between the surface and the spray.

4. RESULTS & DISCUSSION

When the surface is sprayed with room temperature water as shown in Figure 5, there is no noticeable gradient in the heat map which is expected. After the cooled water is sprayed, Figure 6 shows there is an identifiable spray area on the surface. From this image, it was calculated that 30% of the surface was sprayed which was similar to the area measured by hand. The colour difference also shows a visible difference in saturation as well.

This test can be applied in a sanitation or manufacturing process. If a certain coverage percentage and saturation are required, then thermal imaging can be used as quality assurance. As the temperature of the sprayed liquid and the surface are known, areas that are fully saturated or covered would have the same temperature as the sprayed liquid. Temperatures that are close to the spray liquid temperature can be identified as areas that have some spray coverage but are not fully saturated or covered.

4.1 Limitations & Future Work

This experiment showcases the capabilities of using thermal imaging to detect spray areas. However, there are some limitations and areas where the experiment can be improved. First, the quality of the thermal images is dependent on the number of sensors, therefore more detailed images can be taken if a higher-resolution camera is used. This can further improve the reliability and accuracy of the images. This experiment was limited to spraying water on a plastic surface, more test cases should be completed in different ambient temperatures to verify the robustness of the tests. However, as long as there is a sufficient temperature difference the process should work. The temperature of the liquid will also equalize with the surface over time, further tests would need to be completed to find the optimal time to capture the image before temperature information is lost. Future work would also include using a live feed of heat maps to be able to analyze the spray in real-time. This opens up the ability to create threshold alerts which would further increase the monitoring and decision-making capabilities. Addressing these limitations would create a more robust and accurate method for detecting the spray area.

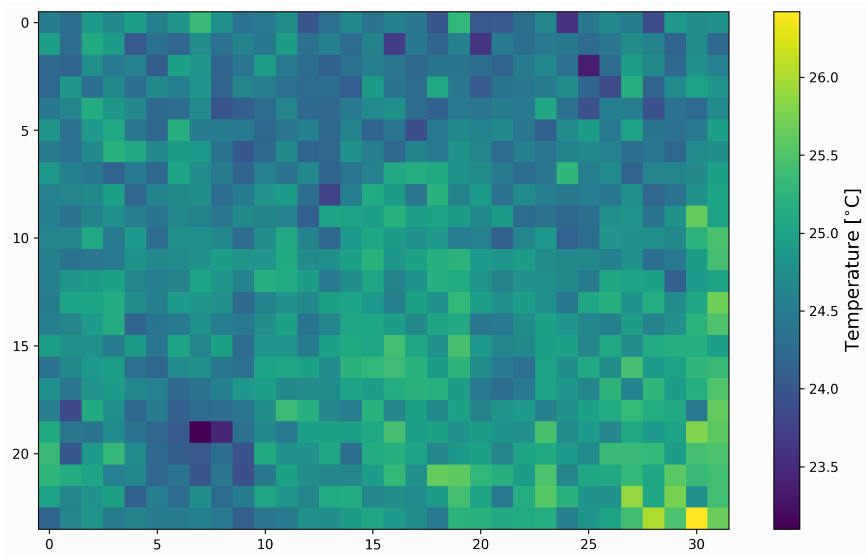

Figure 5. Thermal image of surface sprayed at room temperature

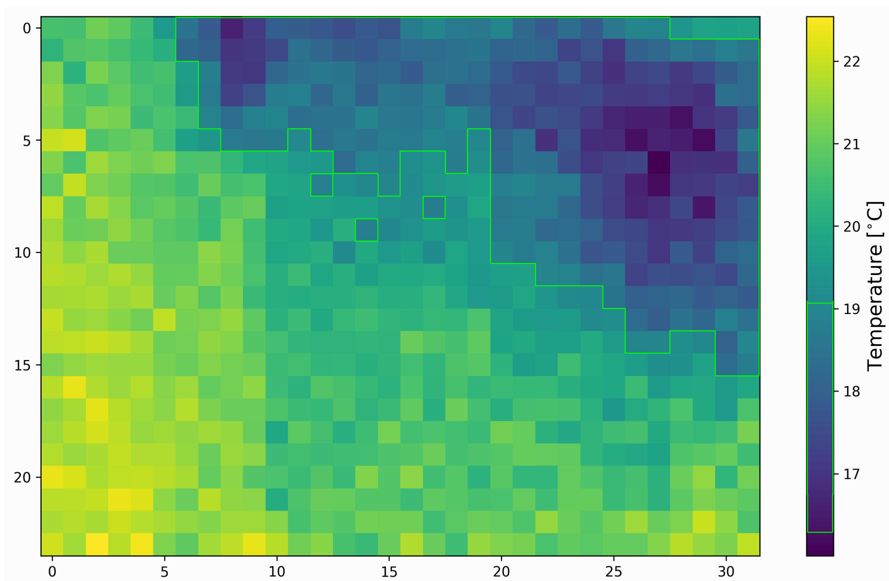

Figure 6. Highlighted thermal map with cooler liquid

5. CONCLUSION

This study explores using a thermal camera to detect the area of sprayed liquid on a surface. A Raspberry Pi 4b and MLX90640 were used to collect the thermal data. The Matplotlib and OpenCV libraries were used to convert the thermal data into heat maps with highlighted areas of interest. Through testing, it is shown that the thermal camera can detect spray areas with a difference of at least 5 deg C. The testing verified that combining thermal imaging with computer vision can be an effective way to analyze the spray coverage of a surface. The experiment can be improved by using a better resolution thermal camera and as well as implementing a real-time feed of the heat maps. This process can be an additional non-instrusive way to verify the quality assurance of any spray process. As long as the temperature difference can be measured, the process allows for an automated system to be developed that can improve efficiencies in spray processes.

REFERENCES

[1] Barbieri, E., Trevisiol, F., Pizzigatti, C., Bitelli, G., and Franzoni, E., "Evaluating water-repellents applied to brick masonry: An experimental study by thermal imaging and water transport properties' characterization," *Construction and Building Materials* **356**, 129319 (Nov. 2022).

[2] Cardenas-Del Campo, P., Soto-Lara, F., and Marin-Granados, M., "Description of Moisture Thermal Patterns in Concrete for the Thermal Inspection Method by Infrared Thermography," in [*International Joint Conference on Mechanics, Design Engineering & Advanced Manufacturing (JCM 2018), 20-22 June 2018*], *Advances on Mechanics, Design Engineering and Manufacturing II. International Joint Conference on Mechanics, Design Engineering & Advanced Manufacturing (JCM 2018). Proceedings: Lecture Notes in Mechanical Engineering (LNME)*, 622–31, Springer International Publishing, Cham, Switzerland (2019).

[3] Bejarin, O. L. and Fajardo, A. C., "Rough Rice Grading in the Philippines Using Infrared Thermography," in [*Computer and Communication Engineering*], Neri, F., Du, K.-L., Varadarajan, V., San-Blas, A.-A., and Jiang, Z., eds., **1823**, 16–26, Springer Nature Switzerland, Cham (2023). Series Title: Communications in Computer and Information Science.

[4] Pugazhendi, P., Kannaiyan, G. B., Anandan, S. S., and Somasundaram, C., "Analysis of mango fruit surface temperature using thermal imaging and deep learning," *International Journal of Food Engineering* **19**, 257–269 (June 2023). Publisher: De Gruyter.

[5] Zheng, Y. and Sun, B., "Power Cable Terminal Fault Detection Method Based on Infrared Thermal Imaging," in [*International Conference on Energy and Electrical Power Systems (ICEEPS 2022), 2022*], *J. Phys., Conf. Ser. (UK)*, 012040 (6 pp.), IOP Publishing, UK (2023).

[6] Durgapurohit, S., Granthi, J., Daware, S., Dange, V., Mhetre, M., and Kadu, A., "Real Time Electric Hazard Detection System Using Thermal Imaging," in [*2022 4th International Conference on Smart Systems and Inventive Technology (ICSSIT)*], 624–629, IEEE, Tirunelveli, India (Jan. 2022).

[7] Song, C., Zang, X., Li, J., Qiao, S., and Zhang, Z., "Defect Detection of Steam Pipelines Using Infrared Thermal Imaging Sensor," in [*2023 2nd International Symposium on Sensor Technology and Control (ISSTC)*], 69–72, IEEE, Hangzhou, China (Aug. 2023).