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# Geometric Calibration of a Thermal Imaging Camera System for Advanced Driver Assistance

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As an international student , I came to the US , leaving my family behind to be able to acquire better education for myself. My main goal is to make a name for myself in the industry and provide research that will be beneficial for the world. I have been fortunate enough to have wonderful experiences along the way. The vast varieties of culture that I have encountered here has had an effect on me as well. My long term goal includes working with an environmental friendly corporation on the upcoming generation of autonomous vehicles.

**Dr. Qin Hu, Eastern Michigan University**

Qin Hu received her B.S. and M.S. degrees in Electrical Engineering from the University of Electronic Science and Technology of China, Chengdu, China, and the Ph.D. degree in Electrical Engineering from Old Dominion University, Norfolk, VA. She is current

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As a descendant from migrated Hispanics and being the first in my family to pursue a doctorate, I am dedicated towards academic achievement. I'm striving to make something of myself and produce research to better the world. In addition to my technical studies, I enjoy learning about culture, history, humanities, and numerous trade skills. My long term goals are to achieve a Ph.D. in the field of Electrical Engineering. Further, I aim to work with a renown university or automotive manufacturer to create the next generation of electric and autonomous vehicles.

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**Abstract**

Traffic accidents claim the lives of millions of people each year. Technological innovations strive to prevent these accidents and have the potential to produce a mobility renaissance. Thermal imaging cameras are known for their capability of providing information about pedestrians and animals in low visibility situations, while RGB cameras can be disabled with insufficient visible light. The sensor-fusion of a thermal imaging camera (TIC) into an autonomous vehicle's (AV) perception-sensor system supports collision avoidance and preventing pedestrian accidents. This system topology would also greatly benefit an AV's performance under extreme weather and environmental conditions, such as total darkness, rain, fog, and dust.

Ensuring that a low-cost, but effective sensor is used to be able to detect warm-body obstacles in the path of the vehicle, this engineering solution would provide proper device initialization and utilization in AV applications. A challenge of this project is to develop a Light Detection and Ranging (LiDAR) and Forward Looking InfraRed (FLIR) thermal imaging system to measure the distance of live bodies on the road. The obstacles presented in the project involve geometric intrinsic and extrinsic calibration of thermal imaging cameras, as the standard black-white checkerboard calibration method used with RGB cameras is not visible to the TIC.

A new geometric calibration method of a thermal imaging camera is discussed, tested and validated in this study. Physical prototypes of thermoelectric cooled and heated pads are utilized to better calibrate the FLIR/LiDAR sensor system. Python was used to develop the calibration algorithms. A depth measurement with the LiDAR/thermal camera was conducted to determine the distance of a pedestrian. This study also overviews the challenges and design constraints encountered.

## 1. Introduction

### 1.1 Statement of Purpose

The goal of the project is to create a calibration solution for the sensor fusion of LiDAR and thermal imaging sensors so a vehicle equipped with this system can have better autonomous obstacle avoidance under extreme weather and environmental conditions [1]. The most critical step to this goal is the intrinsic and extrinsic calibration of the TIC.

This study utilizes Teledyne FLIR's PathFindIR™ II IR camera, as shown in Fig. 1(a), as well as the electronic control Unit (ECU), shown in Fig. 1(b). The camera outputs an NTSC signal to the ECU, which produces a captured video stream with Pedestrian Detection/Animal Detection (PD/AD) function. The analog video signal with PD/AD is then fed to a monitor through a BNC to S-video adaptor. A 12 V DC external voltage source powers this system setup, all shown in Fig. 2.

To obtain digital video streaming from the FLIR camera, a BNC to HDMI adaptor and a Video Capture Card with HDMI to USB were added to the camera system as shown in Fig. 3. The output digital video streaming can be captured by software such as OBS Studio or be saved as video files such as MP4 to computer.


Fig 1. (a) FLIR PathFinder II IR camera; (b) The Electronic Control Unit (ECU).

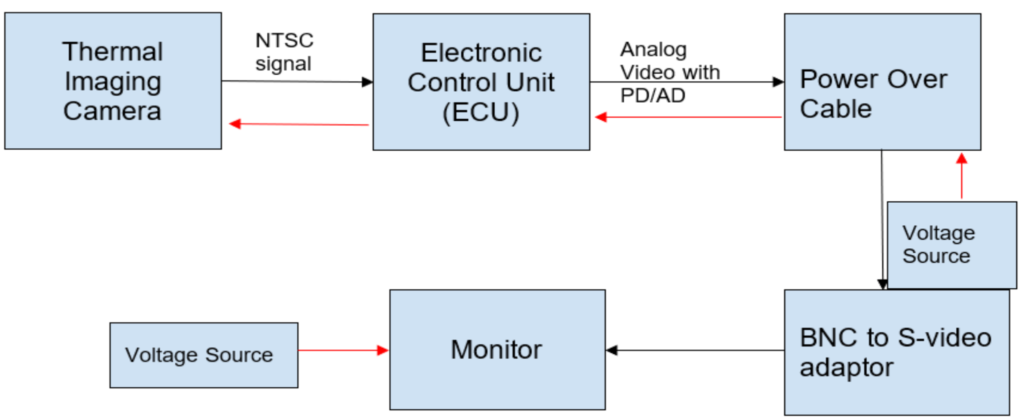


Fig. 2: System architecture of the PathFinderIR II system.

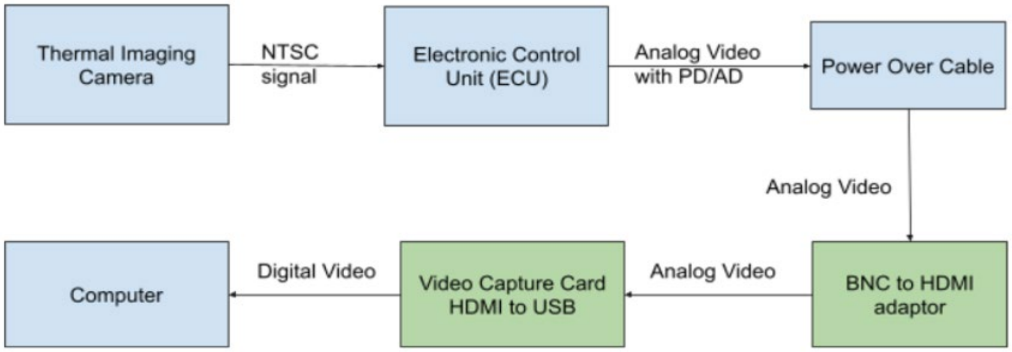


Fig. 3: Modified System architecture of the PathFinderIR II system.

## 2. Experimental Details

### 2.1 Geometric intrinsic calibration

TIC geometric intrinsic calibration is challenging since the regular black-white checkerboard method typically used for RGB cameras, isn't visible to the thermal camera. Various alternative calibration boards were tested, including a heated pattern by hot wire metal, foam metal plates, and sunlight heating of a regular calibration pattern [2]. These alternatives did not provide stable and consistent calibration results, because the heated parts cooled down to the room temperature within 3-5 minutes.

The calibration board used for this project consists of 24 Thermoelectric Cooler (TEC) pads (TEC1-12706), all connected in parallel to two breadboards. The TEC pads are attached to a foam pad, which is used as both a heat insulator and backing. DC voltage (less than 15 V) is provided to the TEC pads to change their temperatures. Their temperature can be higher or lower than the room temperature, depending on the polarity of the DC voltage applied to them. By arranging these TEC squares in a checker pattern, a 9 x 10 checkerboard using TEC squares and a foam board was created as shown in Fig. 4 (a). The results for corner detection of the checkerboard are shown in Fig. 4 (b). The temperatures of the TEC pads measured by a handheld

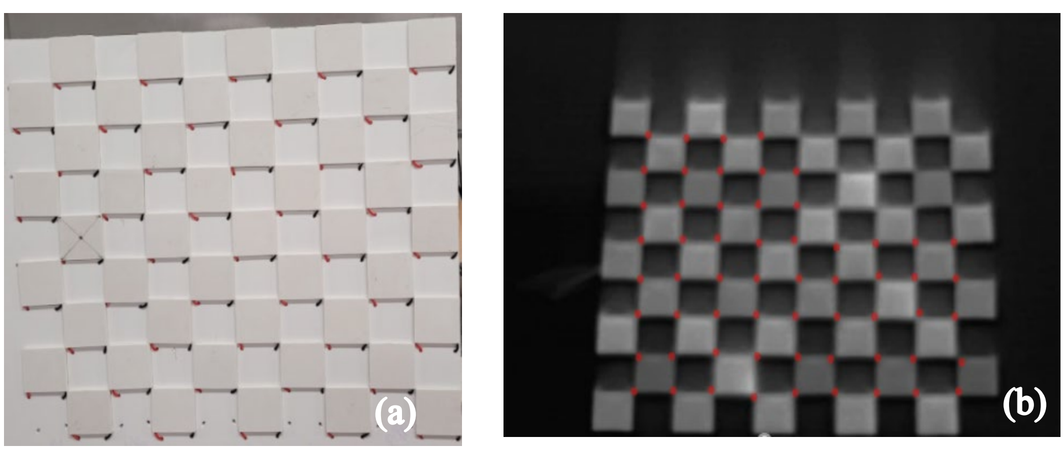


Fig. 4 (a) Checkerboard made by TEC Pads; (b) Corner detection of the checkerboard. Red dots are for corners.

thermometer have a range between 83 and 89 °F. Due to the non-uniform temperatures on the TEC pads, some corners were not sharp enough to be detected.

Instead of detecting corners of the checkerboard, a new calibration board was designed to overcome the non-uniform temperature of the TEC pads. Fig. 5 (a) shows the calibration board with 4x6 circular heated components and Fig. 6 shows the board's electrical wiring. To change the square TEC components into a circular representation, another foam board with holes was overlayed on top of the TEC layer. The image captured by the FLIR camera is shown if Fig. 5(b) and the centers can be correctly detected by our code written in Python (Fig. 5(c)) with OpenCV library [3].

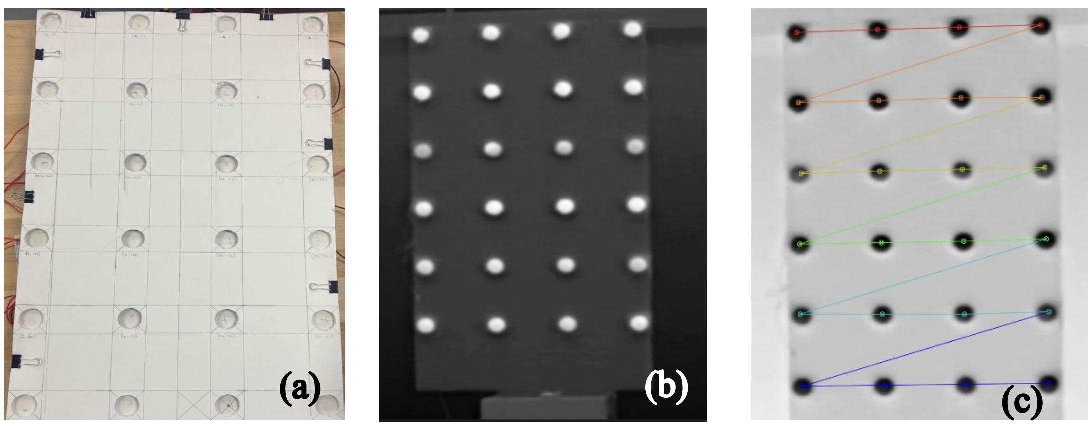


Fig. 5 (a)The calibration board with circular heated components; (b) Image captured by the FLIR camera; (c) circle centers detection in Python.

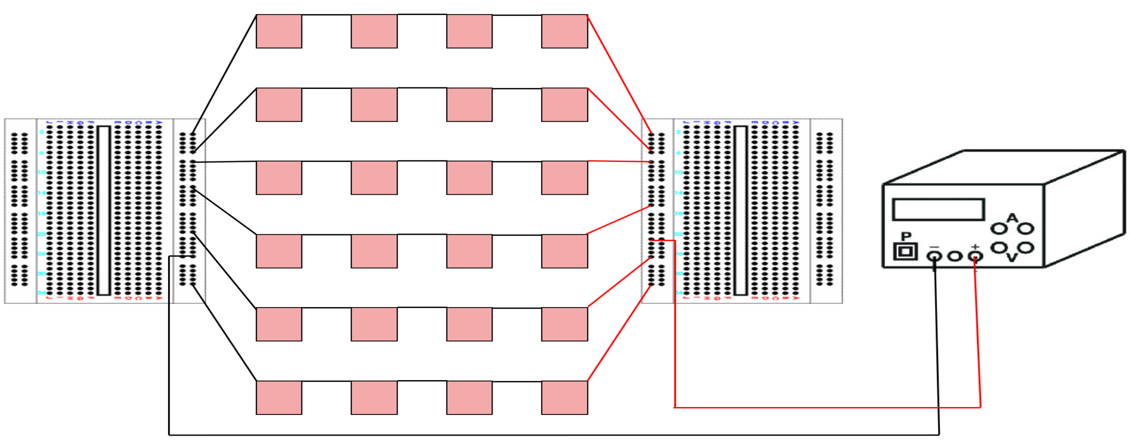

Fig 6. Diagram of the electrical wiring of the calibration board in Fig. 5(a).

The relationship between the 2D thermal image coordinates (u, v) and the 3D word coordinates (X, Y, Z) are shown in Eqn. (1). K is the camera matrix, R is the rotational matrix and T is the translation matrix, all of which are defined in Eqn. (2-4) respectively.

$$[\,u \quad v\,]^T = K[\,R|T\,][\,X \quad Y \quad Z\,]^T \tag{1}$$

$$K = \begin{bmatrix} f_x & 0 & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{bmatrix} \tag{2}$$

$$R = \begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{bmatrix} \tag{3}$$

$$T = [t_x \quad t_y \quad t_z]^T \tag{4}$$

Here, $f_x$ and $f_y$ denote the focal length in $x$ axis and $y$ axis, and $c_x$ and $c_y$ denote the offsets of principal points from the corner of the image frame [4].

Eqn. (1) can be written in to Eqn. (5), with K, R and T included.

$$\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} f_x & 0 & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} r_{11} & r_{12} & r_{13} & t_x \\ r_{21} & r_{22} & r_{23} & t_y \\ r_{31} & r_{32} & r_{33} & t_z \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix} \tag{5}$$

More than 20 different images of the calibration board in Fig. 5 (a) were used to find the intrinsic matrix and the result is shown in Equation (6).

$$K = \begin{bmatrix} f_x & 0 & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} 4999.15 & 0 & 951.38 \\ 0 & 4081.25 & 597.70 \\ 0 & 0 & 1 \end{bmatrix} \tag{6}$$

2.2. Extrinsic Calibration

The purpose of the extrinsic calibration of the TIC is to find the rational and translation matrices for the transformation between the LiDAR and the camera coordinate system [5,6]. To achieve this, the transformation matrix for the camera to the calibration board, and for the calibration board to LiDAR should be determined respectively.

The experiment for extrinsic calibration was set up as shown in Fig. 7 (a). A Velodyne LiDAR VLP-16 is used with the FLIR camera. The calibration board was tilted so that the coordinates of at least two points on each edge of the board can be easily measured by LiDAR. Thus, four-line functions for the four edges based on those points can be easily found, leading to the coordinates of the four corners of the calibration board.

The coordinates of the 24 centers in the camera image are values for [u,v] in Eqn. (5). The actual coordinates of the calibration board with the origin at the upper left corner are used for [X, Y, 0], with Z=0. With the camera matrix found in the intrinsic calibration, the transformation matrix R and T can be determined by our code.

The coordinates of the four corners of the calibration board in the calibration board system can be easily obtained since the length of the board is 22.5 cm and the height of it is 28.0 cm. These coordinates are for $[X_b\ Y_b\ 0]$ in Eqn. (7). The coordinates of the four board corners measured by the LiDAR are for $[X_L\ Y_L\ Z_L]$, as shown in Fig. 7 (b) and (c). The transformation matrix $T_{bL}$ can be calculated by Eqn. (7).

$$[X_b \quad Y_b \quad 0]^T = T_{bL}[X_L \quad Y_L \quad Z_L \quad 1]^T \tag{7}$$

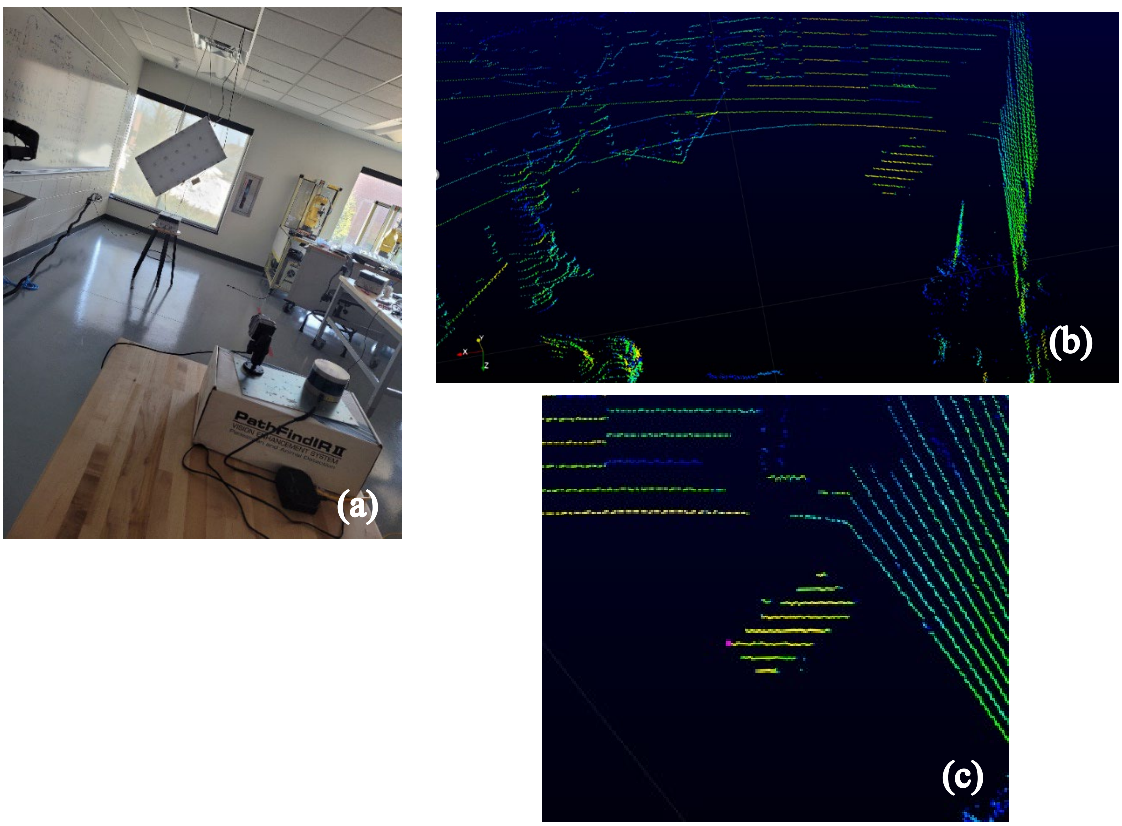


Fig. 7 (a) Extrinsic calibration set up; (b) LiDAR images for the calibration board; (c) Board corners are calculated based on the edge points measured.

## 3. Results and Discussion

The pedestrian detection offered by the FLIR camera is shown in Fig. 8. Fig. 8(a) shows that no people or animals were captured by the camera in front of a store at night. Fig.8 (b) shows that two persons were detected and surrounded by yellow boxes. Our algorithm resolves the centers of the yellow boxes and marks them out by red circles as shown in Fig. 8 (c). The image center coordinates can be realized and used with the transformation matrix obtained in the intrinsic and extrinsic calibration processes.

$$R|T = \begin{bmatrix} r_{11} & r_{12} & r_{13} & t_x \\ r_{21} & r_{22} & r_{23} & t_y \\ r_{31} & r_{32} & r_{33} & t_z \end{bmatrix} = \begin{bmatrix} 0.90565 & 0.42328 & -0.02499 & 68.90222 \\ -0.12809 & 0.21692 & -0.96775 & -70.32348 \\ -0.40421 & 0.87965 & 0.25067 & 104.38855 \end{bmatrix} \quad (8)$$


Fig.8 (a) Image capture without people or animals; (b) Two pedestrians are detected and labelled by yellow frames; (c) Centers of the yellow frames are marked out.

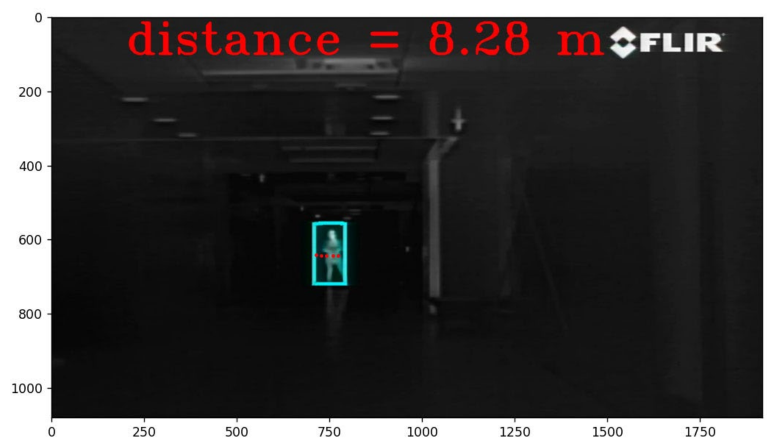


Fig. 9 Pedestrian detected by the FLIR camera, and the distance measured by LiDAR.

The FLIR camera-LiDAR system was set up in the hallway of our school, and the detected distance between the person and the camera was 8.28 m, as shown in Fig. 9. This measurement is very close to the actual distance around 9 meters. The deviation can be reduced by improving the accuracy of the extrinsic and intrinsic matrices.

## 4. Conclusion

A new geometric calibration board utilizing TEC pads with center detection for FLIR thermal imaging camera was developed for testing in this study. The depth measurement of a pedestrian by the thermal camera and the LiDAR was successfully conducted. The future work would be testing of the system on automobile under various incremental weather conditions and non-ideal environment.

## 5. Acknowledgements

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## References

[1] "StackPath," *www.laserfocusworld.com*. https://www.laserfocusworld.com/detectors-imaging/article/14201281/how-thermal-imaging-can-improve-autonomous-driving-sensory-systems

[2] H. Zhang, R. Liu, "Multiple Methods of Geometric Calibration of Thermal Camera and A Method of Extracting Thermal Calibration Feature Points"*, Available at https://henryzh47.github.io/Thermal-Camera-Calibration/*

[3] Bradski, G., 2000. The OpenCV Library. *Dr. Dobb's Journal of Software Tools*.

[4] V. Ayyagari, "Camera Calibration — Theory and Implementation," *Analytics Vidhya*, Sep. 18, 2020. https://medium.com/analytics-vidhya/camera-calibration-theory-and-implementation-b253dad449fb.

[5] F. Itami and T. Yamazaki, "An Improved Method for the Calibration of a 2-D LiDAR With Respect to a Camera by Using a Checkerboard Target," *in IEEE Sensors Journal, vol. 20, no. 14, pp. 7906-7917, 15 July15, 2020, doi: 10.1109/JSEN.2020.2980871.*

[6] Y. Li et al., "Application of 3D-LiDAR & Camera Extrinsic Calibration in Urban Rail Transit," *2020 IEEE 5th International Conference on Intelligent Transportation Engineering (ICITE), 2020, pp. 456-460, doi: 10.1109/ICITE50838.2020.9231446.*