Thermographic and Visible Spectrum Camera Calibration for Marine Robotic Target Detection

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***Abstract*—In the context of detection, location and tracking of human targets with combination of thermographic and visible cameras, this paper addresses the problem of geometric calibration of thermographic and visible spectrum cameras necessary for the stereo perception of targets in the robot frame. A method for precise geometric calibration of thermographic and visible cameras in the autonomous surface vehicle (ASV) ROAZ II is presented. The method combine the utilization of special patterns for intrinsic calibration of thermographic cameras, with the usage of a high-resolution 3D laser scanner for the extrinsic calibration, relating the cameras frames with the robot frame. Calibration process results are presented and analyzed.**

***Index Terms*—Thermografic camera, camera calibration, 3D laser scanner, search and rescue missions**

I. Introduction

The problem of detection and positioning of human targets in autonomous robotic applications has been having increasing attention in recent years. This is a common problem in land scenarios, for example surveillance and intrusion missions, or in maritime environments search and rescue missions.

An efficient method for human detection resorts to thermographic cameras, although its application for relative positioning of target in robotic systems requires precise geometric calibration of cameras.

In this paper, we present an approach to calibrate both thermographic and visible cameras with a 3D laser scanner.

A thermographic or infrared (IR) camera is a device that uses infrared radiation to form an image, in the same way as a normal camera uses visible radiation to form an image. While the visible spectrum cameras operate in ranges between 450-750 nm, the IR cameras operate in wavelengths of 14 nm [2].

The infrared energy is just a portion of the electromagnetic spectrum, that covers the radiation of radio waves, microwaves, visible light, ultraviolet, gamma-rays and x-rays. There are all related and differentiated by the wavelength. All the objects emit a certain radiation quantity of the black body in function of its temperature. Generally speaking, the higher the temperature of an object, the greater will be the IR radiation emitted by the body.

A thermographic camera is able to detect the infrared radiation the same way a normal camera is able to detect visible light. This camera works even in a dark environment, since the light level in the environment does not interfere. Therefore is possible to operate in environments of hard visibility.

Currently is possible to find these cameras in several areas like nocturnal vision, firefighting operations, military target detection, anti-terrorism, pollution prevention and detection, being highlighted search and rescue operation and find subjects in total darkness environments [3].

The developed camera calibration is to be applied both in the land based environment on the autonomous ground vehicle TIGRE[19] and on maritime scenarios with the ROAZ [4] autonomous surface vehicle.

On the ROAZ II the infrared camera is to be used in combined with the visible spectrum ones for search and rescue missions in the detection and tracking of people on the water.

Fig. 1. **Left**: ROAZ II - Autonomous Surface Vehicle (ASV). **Right**: TIGRE - Autonomous Ground Robot for Outdoor Exploration

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In maritime scenarios, the environment can be considered plane (with few obstacles) and with homogeneous temperature on the surface. These allow the detection of the target, essentially, by the difference of the IR radiation level (see fig. 2).

Systems with multiple cameras involving combination of IR and visible spectrum cameras, are excellent platforms for computational vision applications. The efficiency of these systems has been shown in several tasks such as thermal analysis, object detection and human tracking [8][9][10][11].

In order to determine the relative location of a target is essential to perform a precise and efficient method of geometric calibration. Calibration can be used to remove distortion and rectify images as well as obtain the extrinsic camera parameters (camera pose).

For the geometric calibration of visible spectrum cameras there are developed tools which allow to obtain good results [5][6][7]. In general, with these tools are used boards with calibration patterns that are not detected by IR cameras.

Fig. 2. **Left**: Thermografic image view from a person floating in the water. **Right**: Visible spectrum camera view of the same thermographic image instant.

Therefore, a problem emerges consisting on the need to develop a calibration process, with a perceptible patterns for both types of cameras, precise and preferably with low human intervention in order to minimize the errors. The simplicity and efficiency of the process is crucial because the IR camera used is mounted in a pan-tilt unit (with two degrees of freedom). Therefore it is convenient to have a quick process to calibrate the extrinsic parameters, whereas that every time the robot starts and turns on the camera, calibration is needed.

The rest of the paper is organized as follows: Section II details the problems associate to the estimation of the intrinsic and extrinsic parameters from thermal and visible spectrum cameras. Section III enumerate the calibration methods for thermographic cameras. Section IV presents the procedure to estimate the camera parameters for both cameras with a laser scanner. Finally, conclusions are drawn in Section V.

II. Problem Description

Combining thermal and visible spectrum cameras could be effective in tasks such as maritime search and rescue missions (see fig. 2), so it is crucial to ensure an accurate and efficient geometric calibration procedure. The problem associate to the estimation of this parameters to a visible spectrum camera is a well known solved problem. The question is how can we extended this methods in a feasible way to thermographic cameras. The proposed method must be able to support the following constraints: different field of view between thermographic and visible spectrum cameras and robust to pan and tilt cameras.

III. Thermografic calibration methods

In the following section we will detail the more relevant calibration methods able to support the constraints imposed by the thermographic cameras.

One of the approaches used, resorts to a calibration chessboard pattern heated with a flood lamp for a few seconds[12]. This pattern is very popular in the calibration of visible spectrum cameras and has been demonstrated its efficiency[5]. However for thermographic cameras this process causes problems due to the temperature starts to become uniform in front of the patterns after a few seconds of use, making this process rather inefficient (see fig. 3 left).

Another similar but more robust method is present in [13] by making use of a black plastic board with a regular pattern of holes and with a miniature bulb attached behind each hole. With this board the heat dispersion though time is less (see fig. 3 right). This method uses the Caltech Matlab Calibration Toolbox[6], being the major drawback the human intervention requirement in the pattern extraction through the collected images.

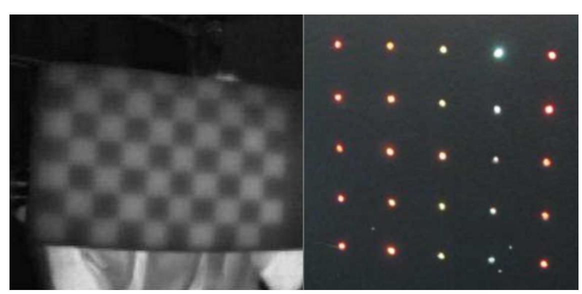

Fig. 3. Heated chessboard (left)[12] and plastic board with bulbs (right)[13]

In [1] is proposed another method to reduce the lack of accuracy imposed by the previous methods[12][13]. The major difference between the previous methods and the new one is the calibration pattern with a grid of squares with the same size cut out of a thin material, opaque and held in front of a warm computer monitor. In this method is possible to see that the heat dispersion is smaller (see fig. 3). In this method is used the toolbox OpenCV-Based Multi-Modal Camera Calibration System[16] that allows the calibration of IR and visible spectrum cameras. The toolbox contain OpenCV libraries for patterns search, distortion modeling and calibration of the intrinsic and extrinsic camera parameters. Includes a near-optimal algorithm for frame selection in which removes the need for the user to choose the frames for calibration manually. Furthermore, to make the simultaneous multi-modal calibration easier, the algorithm includes an alternative pattern search, conceived to locate with precision a calibration mask (in this case the chessboard pattern).

IV. Laser Based Calibration

The calibration procedure that will be present in this section is support by a 3D laser scanner to improve not only the accuracy of the camera parameters estimation but also to ensure a more fast method. The figure 4 presents the system setup from the vision sensors for which we pretend to estimate the extrinsic parameters. The vision perception of each sensor are available in figure 5 as well as the 3D laser scanner that will be used to extract 3D positions common to both cameras.

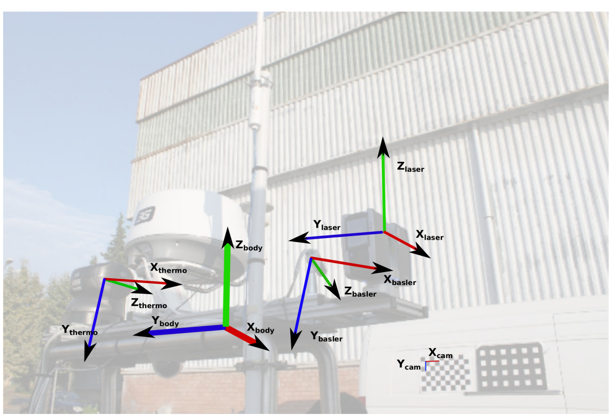

Fig. 4. Coordinate frame for extrinsic camera estimation

A. Hardware

- The Faro $Focus^{3D}$ is a terrestrial laser scanner that outputs, at high speed and resolution, photo-realistic 3D measurements of its surroundings. It is one of the most compact and affordable 3D laser scanner available in the market. The $Focus^{3D}$ uses phase shift technology to measure the distance to the objects. This technology consists in projecting constant waves of infrared light of varying length outwards the scanners, this signals when in contact with an object are then reflected back to the scanner. The phase shift between the emitted and received infrared signals is used to accurately determine the distance of the scanner to the object. With a range up to 120 meters and a measurement accuracy of ±2mm, the Faro $Focus^{3D}$ as the ability to produce reliable and accurate maps specially at close-range. The Scanner was configured to perform a scan with the maximum angular resolution, which results on a resolution of approximately 3mm at a 10 meters distance.
- The visible spectrum camera used was the Basler acA1300-30gc at 15 frames per second (fps), each with a pixel resolution of 1278×958.
- The thermographic camera used is the THERMAL-EYE 5000XP with a resolution of 320x240 pixels, a minimum focusing distance at 8 meters and a field of view of 24ºx18º$(f/1.0)$. The imagery acquisition from the camera is made through a frame grabber (Sensoray s2255).

B. Intrinsic parameters

Both cameras, thermographic and visible spectrum camera, are modeled by the classical pinhole model. Therefore, if we assume a zero skew and a point in the camera $p_i = [u_i, v_i]$ image frame, a point $P_i = (X_i, Y_i, Z_i)$ will be given by $z \cdot [u_i, v_i, 1]^T = K_i \cdot P_i$, where $K_i = \begin{bmatrix} f_x^i & 0 & u_{i_c} \\ 0 & f_y^i & v_{i_c} \\ 0 & 0 & 1 \end{bmatrix}$ is the intrinsic parameters from the thermographic camera, f_x^i, f_y^i is the focal length in pixels for both directions, (u_{i_c}, v_{i_c}) is the main point and z is the scale factor[20].

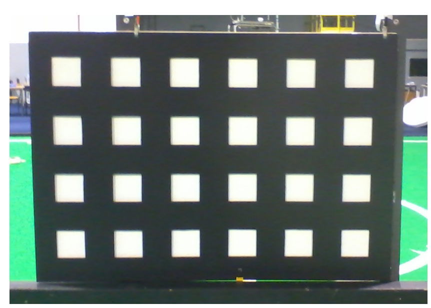

Fig. 6. Pattern wrapped in K-Line

The calibration requires the acquisition of several pattern images in different positions and ensuring that is

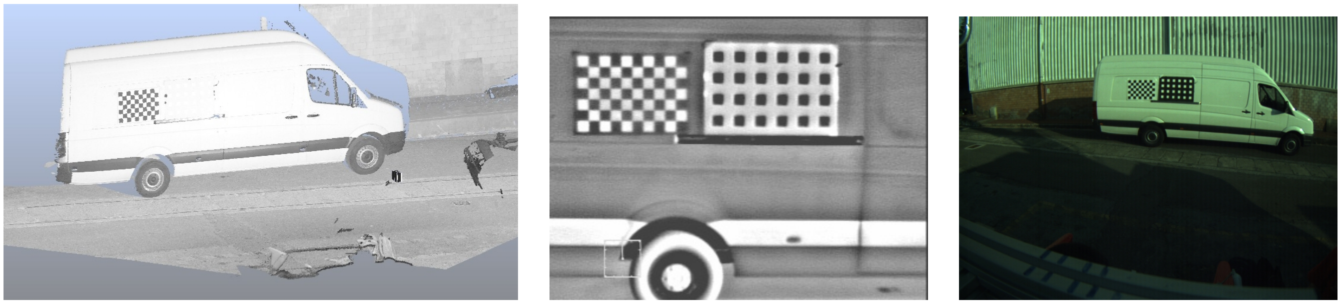

Fig. 5. **Left**: Laser scan image from Faro. **Middle**: Thermographic image with a chessboard patern. **Right**: Visible Spectrum Camera image

filling the biggest area possible of the plane image. The higher the images number, the greater is the possibility of the corners being extracted with precision of the images for calibration. In figure 7 can be found examples of obtained results for a approximated distance of 6 meters in an indoor scenario.

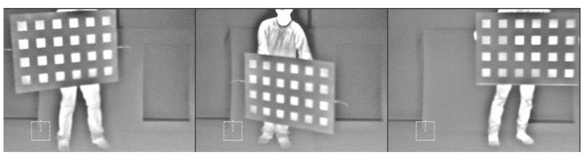

Fig. 7. Acquired images with different poses

Using the calibration toolbox in the previously extracted images were obtained the intrinsic camera parameters. In Figures 8 and 9 can be found the extraction results of the the pattern and rectification, respectively.

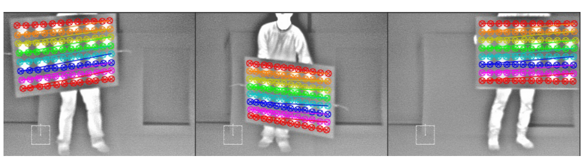

Fig. 8. Pattern's squares extraction

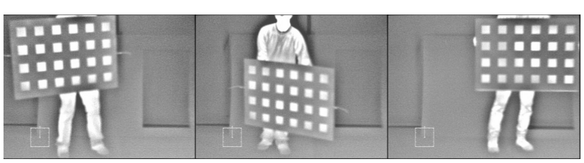

Fig. 9. Rectified images

C. Extrinsic parameters

In order to estimate the extrinsic parameters, the common procedure to estimate the rigid transformation parameters requires putting a calibration chessboard in front of both cameras (see fig. 5). For the proposed scenario this procedure could not be implemented due to the field of view from each camera and the defined plane π as that would require a large chessboard to ensure that corners are detected with higher accuracy, specially in the visible spectrum camera. Considering the constraint, the solution is to extract points in both cameras based on the the laser scanner extracted points(see fig. 5 right) and triangulate their 3D positions. Then, using the least-squares method it is possible to estimate a 3D plane equation in the stereoscopic coordinate system, assuming the center of the body as the 3D position $(0, 0, 0)$ (see fig. 4). This method makes it possible to obtain the extrinsic parameters relating the world coordinate frame and the camera coordinate frame, defined by a rotation R_i and translation T_i, see coordinate frame figure 4.

Both feature attributes and the epipolar constraint will be used to evaluate the correspondence between points detected in each camera. In order to meet the epipolar constraint: $P_i^T K_i^{-T} E K_j^{-1} P_j = 0$ where the essential matrix is $E = \hat{T}_j^i R_j^i$ and the relative rigid transformation parameters between cameras are defined as $R_j^i = R_i R_j^T$ $T_j^i = T_i - R_j^i T_j$ [20].

D. Error Analysis

To evaluate the results obtained from the calibration, we performed different calibration sequences to examine the method's effectiveness:

- **Test 1**: Keeping a fixed camera position and acquire twenty images in different instants of time. The obtained results were as follows:
- **Test 2**: Changing the pan and tilt angles and placing the camera in a same known position and compare the obtained results.

V. Conclusion

In this paper is presented a proposal for calibration of both thermographic and visible cameras.

TABLE I
STANDARD DEVIATION OF THE ORIENTATION DEGREES AND RELATIVE CAMERA POINT IN THE BODY REFERENCE FRAME

Roll	0.00003 rad
Pitch	0.00580 rad
Yaw	0.00967 rad
P_x	0.00366 m
P_y	0.04077 m
P_z	0.02456 m

TABLE II
STANDARD DEVIATION OF THE ORIENTATION DEGREES AND RELATIVE CAMERA POINT IN THE BODY REFERENCE FRAME

Roll	0.00220 rad
Pitch	0.01045 rad
Yaw	0.00547 rad
P_x	0.00756 m
P_y	0.02131 m
P_z	0.01119 m

For the calibration process, different calibration patterns were tested. It was also analyzed the precision of the calibration due to the thermographic camera used in the vehicle being mounted in a pan-tilt without its pose return.

Knowing the intrinsic and extrinsic camera parameters makes possible the implementation of a visible spectrum and thermographic vision system for human target detection and tracking, as well as the determination of its relative position in the robot coordinate reference frame.

Future work, will address the development of an automatic method, namely the 3D laser points detection and selection, and the automatic fine adjustment of thermographic camera extrinsic for small perturbation in the pan and tilt configuration.

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