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THERMAL VISION INTEGRATION IN MOBILE ROBOT VISION SYSTEM

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Abstract: In order to use the mobile robot platform for human detection and tracking, it is necessary to develop advanced vision system and intelligent top level control algorithm. In this paper integration of thermovision camera in robot vision system and intelligent supervisory control algorithm development for human detection and tracking is presented. The main goal of this research was to enable mobile robot platform to recognize the persons in indoor and outdoor environment, and to localize them with accuracy high enough to allow adequate human-robot interaction. With this approach a person can be detected independently from current light conditions and in situations where no skin color is visible. However, variation in temperature across same objects, blowing winds with different temperature gradients and person overlap while crossing each other, put challenges in thermal imaging and will have to be handled intelligently in order to obtain the efficient performance from motion tracking system. Presented research in this field includes making tracking system more robust and reliable by using the computational intelligence.
Keywords: Robot vision; Thermal vision; Human tracking; Computational intelligence

1. INTRODUCTION

Modern robots move away from factory production lines and towards human everyday life. These systems will require robust algorithms with an adequate artificial intelligence for tracking people to ensure natural and intuitive interaction between human being and robotic systems [1,2,3]. The multiple people tracking problem is well-known in computer vision, where there are developed systems used mostly in surveillance, identity verification, automatic motion capturing and human motion analysis with one or more static cameras. In these environments, moving objects can be easily detected using background subtraction techniques [4,5].

In the case of mobile robots, these tasks become more challenging since the robot is moving and the environment is unpredictable so that background subtraction methods cannot be applied. For robots providing support to disabled people, being companions of elderly people or mobile robots acting as co-workers of humans in inspection of contaminated/hazardous environments systems should be robust due to increased noise and moving background. Aside that systems need to be fast so the robot can work in real-time and non-invasive so the normal human activity can be unaffected.

Robots that work in the same environment with humans do not only need to identify humans but they also need to track their motion in order to avoid collision with them or to follow them. The main goal of this research was to develop mobile robot platform that can follow person and avoid obstacles on its path. Most of the systems for detecting and tracking people on a mobile robot use either range sensors such as laser scanners and ultrasonic sensors or a color camera as the primary sensor [6,7]. Thermal vision helps to overcome some of the problems related to color vision sensors, since humans have a distinctive thermal profile compared to non-living objects and there are no major differences in appearance between different persons in a thermal image. Another advantage is that the sensor data does not depend on light conditions and people can also be detected in complete darkness.

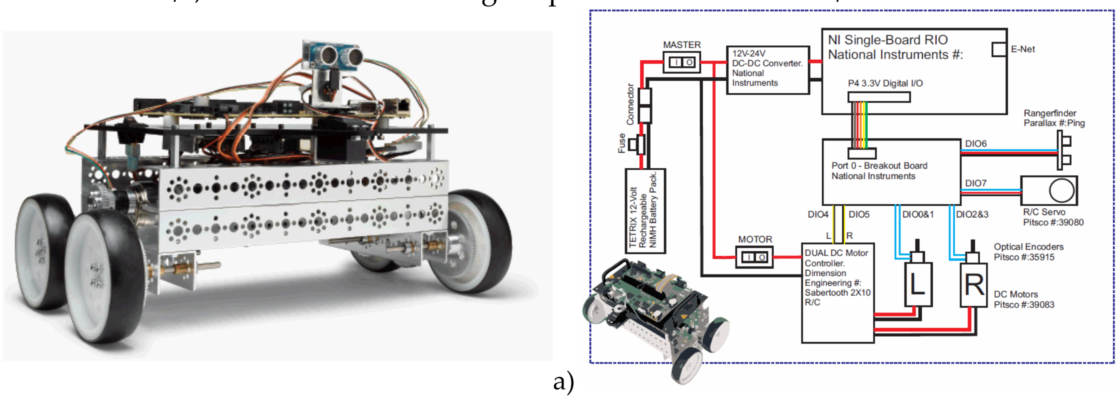
In this paper the aim is to develop computationally intelligent control algorithm that enables robust and reliable human tracking by mobile robot platform. The core of the recognition methods proposed is intelligent classifier that detects human and its location in every frame acquired by thermovision camera. The classifier determines whether the region of interest is human or not based on features extracted from the processed thermal image. Besides the proposed reliable computationally intelligent human tracking algorithm, in this paper future use of computational intelligence techniques in robotic thermo-vision is also briefly discussed

2. EXPERIMENTAL SETUP

2.1 DaNI robot

For development of reliable mobile robot platform that is capable of tracking people based on thermal image National Instruments Robotics Starter Kit 1.0 has been used. NI Robotics Starter Kit 1.0, known as DaNI robot (Fig. 1a) is a mobile robot platform that features sensors, motors, and NI Single-Board RIO hardware for embedded control [8]. DaNI is a four-wheel robot, powered with two motors and equipped with ultrasonic distance sensor for distance measurements. The Block diagram of LabView Robotics Starter kit is shown in Figure 1b.

The NI sbRIO-9632 embedded control and acquisition device integrates a real-time processor, a user-reconfigurable field-programmable gate array (FPGA), and I/O on a single printed circuit board (PCB). It features a 400 MHz industrial processor, a 2M gate Xilinx Spartan FPGA, 110 3.3 V (5 V tolerant/TTL compatible) digital I/O lines, 32 single-ended/16 differential 16-bit analog input channels at 250 kS/s, and four 16-bit analog output channels at 100 kS/s.



a) b)

Figure 1. DaNI robot (a) and Block diagram of LabView Robotics Starter kit (b)

It also has three connectors for expansion I/O using board-level NI C Series I/O modules. The sbRIO-9632 offers a -20 to 55°C operating temperature range, and includes a 19 to 30 VDC power supply input range, 128 MB of DRAM for embedded operation, and 256 MB of nonvolatile memory for storing programs and data logging.

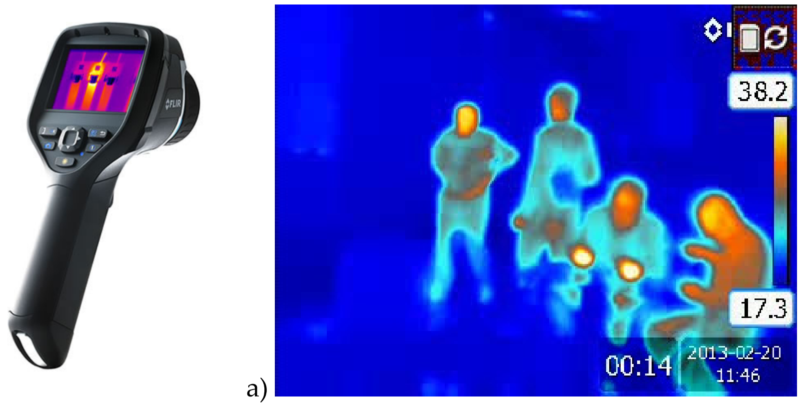
The Parallax ultrasonic distance sensor can detect obstacles for distance measurements between 2 cm and 3 m. The ultrasonic sensor detects objects by emitting a short ultrasonic burst and then “listening” for the echo. Under the control of a host microcontroller (trigger pulse), the sensor emits a short 40 kHz (ultrasonic) burst. This burst travels through the air at about 1130 feet per second, hits an object, and then bounces back to the sensor. The PING))) sensor provides an output pulse to the host that terminates when the echo is detected; hence, the width of this pulse corresponds to the distance to the target.

The mobile robot platform has a built-in 10/100 Mbit/s Ethernet port that can be used to conduct programmatic communication over the network and host built-in Web (HTTP) and file (FTP) servers. The programming of the sbRIO-9632 device is done by the LabView graphical development environment. The real-time processor runs the LabView Real-Time Module on the Wind River VxWorks real-time operating system (RTOS) for extreme reliability and determinism.

LabVIEW contains built-in drivers and APIs for handling data transfer between the FPGA and real-time processor.

2.2 Thermal image information

The experimental mobile robot platform was equipped with an array of sensors including a thermal camera FLIR E50 shown in Figure 2a. The camera can detect infrared radiation and convert this information into an image where each pixel corresponds to a temperature value [9] (see Figure 2b).



a) b)

Figure 2. FLIR E50 thermal camera (a) and thermal image (b)

The resolution of the thermal camera is 240 × 180 pixels, so total number of the pixels is 43,200. The thermal sensitivity of the camera is less than 0.05°C and the accuracy is ±2°C or ±2% of reading within the temperature range from -20°C to 650°C. The frame rate is 60 Hz and operating times 4 hours. The weight of thermal camera is 0.825 kg and that is not neglectable but it doesn't significantly affect the mobile robot platform dynamics.

The robot was operated in an unconstrained indoor environment (a corridor and a hallway at our Faculty). Persons taking part in the experiments were asked to walk in front of the robot while it performed two different autonomous patrolling behaviors: corridor following (based on sonar readings) and person following (using information from the implemented tracker), or while the robot was stationary. In our experiments the visible range on the image was equivalent to the temperature range from 17.3 to 38.2 °C and one of predefined six color palettes has been chosen.

3. METHOD

3.1 Fusion of sensor information

In order to enable mobile robot platform to successfully and safely follow people the good idea is to integrate few sensors that can detect environment of the robot. There were attempts to combine color vision or stereo vision and range sensor information to fulfil the tracking task [6]. For this research ultrasonic sensor is used just for obstacle avoidance and thermal image is used for people tracking. The path planning algorithm developed in LabView 2011 (Fig. 3) combines data gathered from both sensors. This way mobile robot platform can track people without collision with obstacles or people.

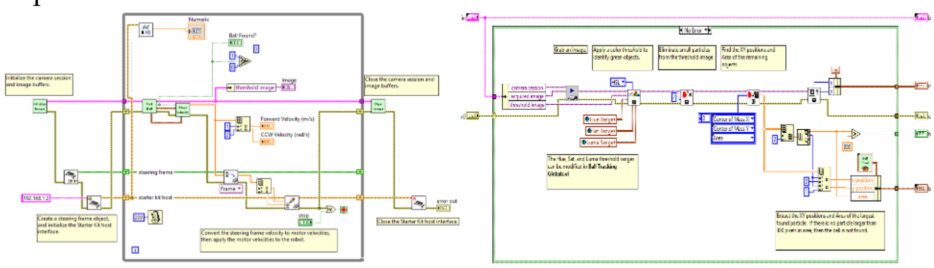


Figure 3. Human tracking and obstacle avoidance algorithm developed in LabView 2011

Thermal camera that is providing visual information about the robotic system's environment is connected to laptop, which was linked with DaNI robot via Ethernet cable. Mobile robot platform was controlled by LabVIEW 2011.

3.2 Thermal image processing

The thermal camera can detect infrared radiation and convert this information into an image where each pixel corresponds to a temperature value. The blue color corresponds to low temperature and high temperature corresponds to yellow color that is a combination of red and green color in RGB image (Figure 4).

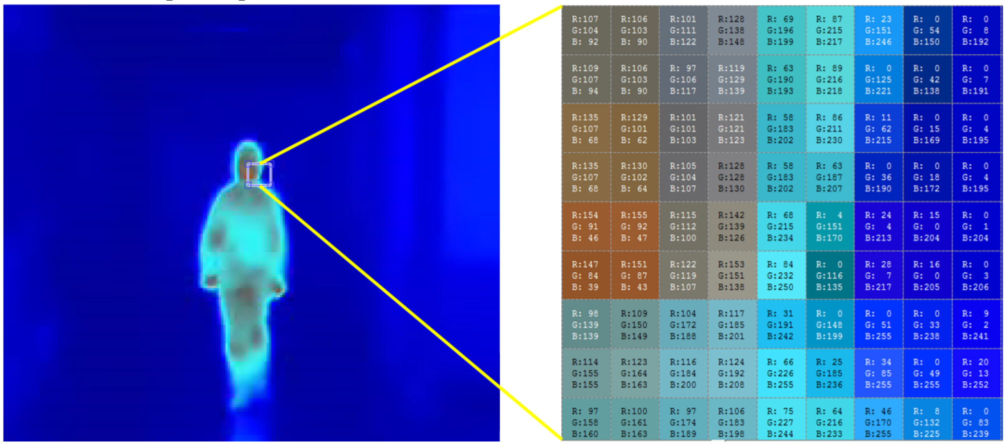


Figure 4. Thermal image and pixel values for selected area

The segmentation algorithm is quite simple in this case. If a pixel color values for red, green and blue are inside set limits, then pixel has a value 1, and otherwise it has value 0. This way a segmented binary image is achieved (Figure 5). The binary image is convenient for feature extraction.

Figure 5. Segmented binary image

3.3 Feature selection and extraction

Once the objects have been segmented different features describing segmented object regions are calculated. The main important feature for human detection is proportionality. The proportionality of a region of connected segmented pixels is ratio between height and width of the bounding box of the segmented region. The bounding box is the smallest rectangle containing the segmented region [1,2].

Other features that are often used to describe objects after segmentation are image moments. Image moment is a certain particular weighted average (moment) of the image pixels' intensities, or a function of such moments. Simple properties of the image which are found via image moments include area (or total intensity), its centroid, and information about its orientation. It is possible to calculate moments which are invariant under translation, changes in scale, and also rotation. Most frequently used are the Hu set of invariant moments.

The recognition of human, using computationally intelligent classifiers, was done based on the proportionality descriptor and first four Hu invariant moments extracted from the resulting binary segmented images. For real world application it is of particular interest to perform object classification reliably and effectively. This means that the applied classifier has to satisfy goals of high recognition accuracy and small computing time. Computationally intelligent classifier - a neural network classifier was considered for recognition and tracking purposes.

3.3 Classification method for human detection and tracking

The ANN used in this study was a standard feed-forward, back propagation neural network with three layers: an input layer, a hidden layer consisting of 10 hidden neurons and an output layer. Input network variables were five features of segmented image, while two network outputs represent probabilities of object belonging to each of the classes – human or not human. For training, the back propagation scaled conjugate gradient algorithm that updates weight and bias states according to Levenberg-Marquardt optimization was used, while the mean squared error was used as a performance measure during training.

The performance of a trained network can be measured to some extent by the errors on the training, validation and test sets, but it is often useful to investigate network response in more detail. One option is to perform a regression analysis between the network response and the corresponding targets.

4. EXPERIMENTAL RESULTS

Two hundred frames randomly selected from 5 different videos taken with different people and in different scenarios were manually analyzed and dataset of 334 objects with five features each was used for training, validation and testing of the ANN classifier. That dataset was randomly divided into training, validation and testing sets. The training set (267 samples) was presented to the network during training, and the network was adjusted according to its error. The validation dataset (43 samples) was used to measure network generalization, and to halt training when generalization stopped improving. Finally, the testing dataset (24 samples) had no effect on training and so provided an independent measure of network performance. Classification accuracy was above 98%.

To analyze the performance of the recognition and following of human we used results received from a mobile robot platform and LabVIEW (Figure 6)

People detected in thermal image are inside the green bounding boxes, and all the objects that are segmented and not human are inside red bounding boxes. The objects captured by thermal camera installed on mobile robot platform with similar temperature as people were for instance hot tea and coffee cups and different heating sources like air condition devices. A major difficulty for all tracking systems involving multi-target tracking is the problem of occlusions. The tracker is able to detect and track multiple persons but the performance of the tracking system depends on crossings and occlusions.

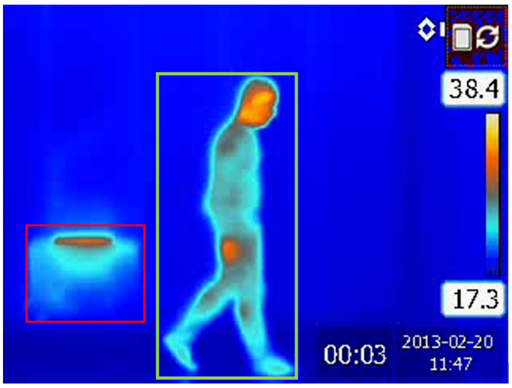


Figure 6. Human detection in thermal image by mobile robot platform

5. CONCLUSION

This paper presented a people tracking system for mobile robots using thermal vision. The system uses a robust and fast tracking method based on a neural network classifier. Reliable features extraction is necessary for the full use of all benefits of a neuro classifier which is the core of the recognition method proposed in this paper. The results indicate good detection performance and consistent tracking in the case of single persons. The tracker is also able to detect and track multiple persons. The performance of the tracking system here depends heavily on the intensity of interaction between persons. The tracker tends to easily lose the track in such cases but it recovers quickly from tracking failures. Future work would include incorporating other cues such as color appearance models of persons to improve data association and resolve occlusions.

Experimental results show that this kind of approach in robot vision for human detection and tracking gives good results. Using the fact that neural classifier can handle different types of objects, and on the other hand classifier made decisions which are reliable and accurate, algorithm used in paper can be implemented in different tasks for mobile robot platform with thermal vision.

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