IRLeak: Continuous Low cost Virtual Audits Using Thermal Imaging

ABSTRACT

Energy wasted in residential and commercial buildings from open and leaky windows, open refrigerator doors, and switched-on computers account for a large fraction of the energy budget of a country. It is estimated that energy wasted by 75,000 homes in the US is equivalent to the British Petroleum Inc. Gulf oil spill hazard. Energy audit systems provide a remedy to this problem where certain types of energy wastage due to leakages and poor insulation can be analyzed and addressed. However, there is a critical need for low cost systems that can *continuously* monitor such wastage and provide recommendations to users to mitigate such wastage. To this end, in this paper we present a low cost thermal imaging system that can detect open and drafty windows, open refrigerator doors, open microwave doors, and computers left accidentally switched on, as well as humans in the room. The system comprises a low resolution, low cost (16×4) IR camera and a low cost digital camera mounted on the steerable platform. It automatically scans a room and takes low resolution IR and RGB images at a low frequency. It then uses image stitching and a segmentation algorithm to determine temperature hotspots in the room. Finally, it uses pre-captured data on the surface temperature of different appliances as well as windows to determine anomalous energy usage. The system obviates the need to equip every appliance with an energy meter to detect anomalies and costs less than \$30. The preliminary evaluation shows that the system can reliable detect these anomalies and can also be used for occupancy detection.

1. INTRODUCTION

It is estimated that energy wasted in 75,000 US homes in one year is equivalent to the energy loss due to the British Petroleum oil leakage [?]. A portion of this energy wastage can be attributed to callous use of appliances—open refrigerator doors, open microwave doors, and televisions and computer switched on when there is no one in the room, and open doors and windows. The other portion can be attributed to poor insulation and leaky and drafty windows. While poor insulation can be addressed through energy audits, it is more challenging to determine wastage due to careless use of appliances and windows/doors. It requires continuous monitoring of such events using a low-cost non-intrusive sensing system.

A plausible solution to the problem is energy metering. Every appliance can be instrumented with energy meters and analytics on the energy consumption data can determine anamolous usage. Unfortunately, however, energy meters are usually expensive and blanket covering a home with energy meters can be prohibitively expensive. Energy disaggregation on data from a single point is another solution whose accuracy is limited if the number of appliances are large and the sampling rate is low [?] To address this problem, in this paper, we present the design and preliminary evaluation of a low cost thermal imaging system that uses a single low resolution IR and RGB camera to determine energy consumption hotspots in a room.

Our system, **IRLeak** comprises the two cameras mounted on a steerable base and scans a room at a very low frequency. It then uses a combination of image stitching and image segmentation to determine temperature hotspots in the room. The system can overlay panoramic views of the thermal images with the digital images to provide a visualization of the energy hotspots in the room. It then uses pre-collected temperature profiles of different appliance surfaces to determine which appliance is being used anamolously. The system can also determine the occupancy of the room. The overall systems costs only \$30, and a single camera suffices for a room. Through a preliminary evaluation using an experimental setup in the lab, we show that **IRLeak** can accurately find open windows, doors, open refrigerator door, open microwave doors, and switched on computers and televisions.

Research Contributions

The design, implementation, and evaluation of **IRLeak** presents the following research contributions.

- **A low-cost virtual audit system**. **IRLeak** is a low cost thermal imaging system that can determine anamolous use of appliances and energy wasted due to open windows and doors. It obviates the need to instrument appliances with individual energy meters. We develop a simple image segmentation and processing algorithm that can reliably detect temperature hotspots in the room. This provides the ability to collect longitudinal data on energy wastage of homes.

- **Functional prototype and Evaluation**. We have developed a fully functional prototype of **IRLeak** and present preliminary evaluation on the accuracy of detecting anomalous appliance use, human occupancy detection, and detecting open windows. We show, using a laboratory setup, that **IRLeak** is highly accurate inspite of its simplicity.

2. SYSTEM OVERVIEW

The overview of the system has been described in 1. The system has two major components - Complete Camera Module and the Image Processing Unit. The Complete Camera Module (CCM) consists of the IR camera, Digital camera and the Motor modules. All three modules are controlled by a Raspberry Pi. The motor rotates by a pre-calibrated angle and both the digital and infrared images are taken simultaneously and sent over to a PC where the Image Processing Unit (IPU) is present. The first task of IPU is pre-processing images and generate the heat maps for the thermal data. In the training phase the digital images are stitched together and the same stitching mechanism is applied for the IR images in testing phase. Processed images give the thermal layout of a wall surface which can be used for analytics.

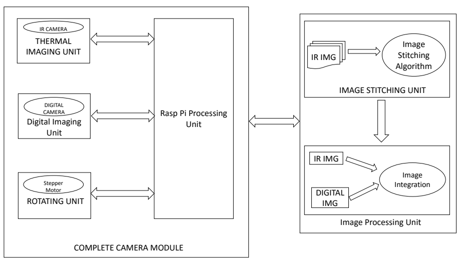

Figure 1: Thermal Imaging System Block Diagram

3. THERMAL IMAGING SYSTEM

In this section we describe the different components of our prototype, *Thermal Imaging System* as shown in Fig. **??**. The two subsystems are the *Complete Camera Module* and the *Image Processing Unit*. We describe the configurations and the operating principles of each of the components below.

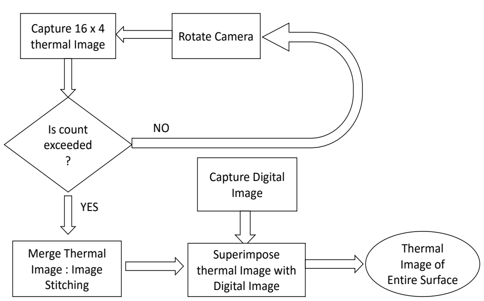

Figure 2: Thermal Imaging System Flow Diagram

3.1 Complete Camera Module

One of our goals in this work is to develop a low-cost IR camera based system for a one-time longitudinal heatmap scanning of an entire room which helps to find the potential air leakages, insulation problems or unattended and anomalous usage of any objects (doors and windows are open for a subtle amount of time or air leakages are quite persistent etc.) and appliances (refrigerator door is kept open, washer is unnecessarily getting heated etc.). While commercially available systems are available to scan through but they are expensive and warrant professionals to operate. Motivated by this, we integrate a low-cost, near zero-power IR camera (MLX90621) [] with Raspberry Pi to build a simple prototype which can be deployed at ease by the home owners, residential and commercial occupants at their own comfort.

The IR camera helps detect the background radiant temperature between -40°C to +85°C with a resolution of 0.02°C and -50°C to -300°C for the object temperature and generates the corresponding heatmaps. We also integrate a digital camera with the circuit board to collect the pictures of the scanned area for mapping the control points of the objects of interest with the heatmaps. We employ a simple image stitching algorithm to map the boundaries and contours of the objects with the heatmaps and validate them with the ground truths as obtained from the digital images. Figure **??** depicts the circuit for the two camera modules.

To achieve a 360° scanning views at a specific angle, we integrate a stepper motor unit with our proposed camera module. The entire camera module is mounted on a case which is rotated by the stepper motor. The stepper motor is calibrated to move at x$^\circ$ every XXX seconds to capture the thermal images. A digital camera is synchronised with the IR camera in-situ to take the images of the surrounding wall surfaces and the objects/appliances as the IR camera scan through. The data from both the IR and digital cameras is stored locally and transferred to the server periodically.

3.2 Image Processing Unit

We propose to use the IR camera in tandem with a digital camera to detect and appropriately map the heatmap's points of interest in contrast to the presence of buildings air leakages, heat dissipation associated with different objects and appliances while achieving high precision and detection accuracy. While the specific color codes of heatmaps help detect the moderate, extreme or regular hot and cold surfaces, augmenting this with digital images helps detect any unusual usage behaviors, and operating conditions of everyday appliances in smart home environment. For example, if a room has multiple windows and doors with air leakages or multiple similar small to medium load appliances, solely the heatmaps may not provide the home owners the adequate information as needed to detect any abnormal energy usage. While the IR camera albeit helps detect the region of interest but fails to provide the detailed identifications of the similar type of objects and appliances.

We develop a basic image stitching algorithm to solve this problem. We address the image displacement problems from two differing image sources and stitch the heatmaps and digital images collectively to create a complete panorama such that it can provide meaningful feedback to the tenants for their corrective actions. First we stitch together the overlapping digital images and create a single panoramic image. Subsequently, we use the thermal images from the IR camera and stitched them together. We use the Hugin tool [**?**] for this thermal image stitching purpose. Figure 3 represents the individual digital image-stream as baseline. The stitched image and thermal mask are also shown in Figure 4.

We employ the digital stitching procedure to create the thermal panorama. We first stitch the digital images and maintain the respective control points for the stitching procedure which we reemploy to process the stitched thermal image generation. Next we augment the digital image in the background of the stitched thermal image based on the respective control points as shown in Figure 4 (b). We use a hybrid image construction methodology where the mask image or the thermal image is passed through a low pass filter and the digital image is passed through a high frequency filter to construct the digital image augmented heatmaps. A complete procedure of the this image processing step have been described in Algorithm 5.

4. PRELIMINARY EVALUATION

5. ANALYTICS

In this section we discuss the analytic done using the panoramic thermal images. We perform initial set of experiments which includes discerning among cold surfaces, hot surfaces and human bodies. We also articulate the challenges involved which frame our future goals for upgrading the system. We noted down the temperatures of the different surfaces which are stated in Table 5.

Object	Temperature (F)
Background/Wall	73
Human Body 1	83
Human Body 2	81
Fridge	50
Heater	100

Table 1: Temperature of different Surfaces

5.1 Experiment 1: Discerning Human body and Open Fridge

In this experiment we aim to find a human body and an open refrigerator, where the inputs are Figure 7. There are three thermal regions in the image - background, open fridge and the person. The image that needs to be segmented is the stitched IR image and the objective is to create a thermal mask which separates the hot and cold regions from the background. This is possible because of the careful settings of the color palette for the thermal images. We ensure that the background has darker tones than the hot or cold surfaces which helps achieve the desired segmentation after image binarization using Otsu's method [5]. We apply a 7×7 neighborhood 2-D median filter to eliminate small blobs and get the few major thermal zones. Next step is to find the contour and their location of the blobs and then for each blob the average temperature is computed and the lookup table 5 is used to identify the object closest to that temperature. A pseudocode for the entire procedure has been given in 6.

5.2 Experiment 2: Discerning Two Human bodies and an Open Fridge

5.3 Experiment 3: Discerning Two Human bodies and a Running Portable Heater

6. CONCLUSION AND FUTURE WORK

7. REFERENCES

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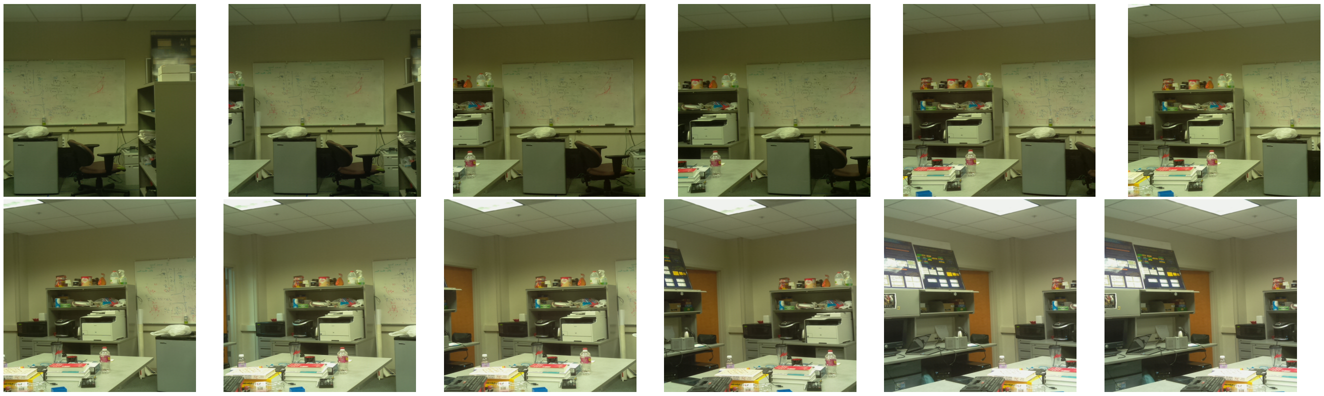

Figure 3: Baseline Stream of Images

Figure 4: Stitched Result for Baseline Stream of Images

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Procedure IPU(Input:  Individual set of baseline digital
  images(D) and corresponding thermal images (I))
Output:  Thermal Panoramic Image
1.  Create panoramic image for the
 baseline digital images using Hugin tool
2.  Replace the digital images with the thermal images
  and load the saved project again to construct the
 panoramic thermal image
3.  Employ High pass filter on the digital image
4.  Employ Low pass filter on the IR image
5.  Combine the two to get masked thermal image
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Figure 5: IPU procedure

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Procedure Hot and Cold Zone Segmentation(Input:
Constructed panoramic thermal image (I)
Output:  Matched Thermal Regions
1.  Apply Otsu's thresholding
2.  Find the contours of the hot and cold regions
3.  Match the internal temperatures with the
LIST OF SURFACE TEMPERATURES
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Figure 6: Thermal region identification: Two object case Hot and Cold

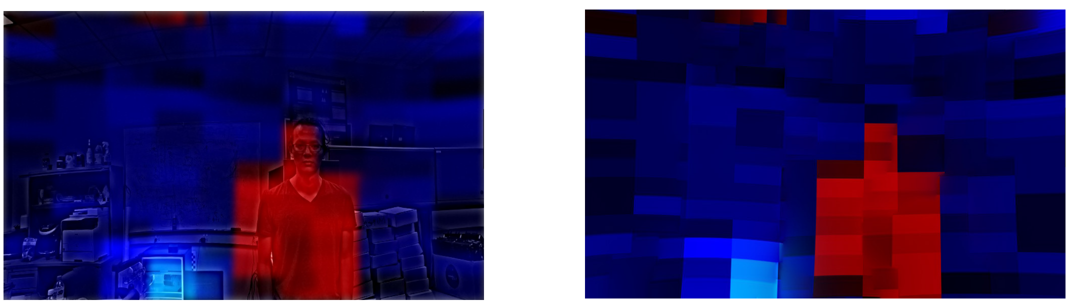

Figure 7: Stitched Image: Fridge and Human body