Infrared Imaging Sensor Brick for Modular Robotics

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Abstract

In this project of "Infrared Imaging Sensor Brick for Modular Robotics" we will design and build a completely packaged thermal sensor brick based on the concept of modular sensor bricks. The thermal sensor brick will house in a 21" x 17" x 5.25" box of aluminum built by us for it. The brick will have a single ON/OFF switch, and operate on power drawn from one single 12V battery source. The package will also be robust enough to be both airline and land travel compatible. The design of the brick will be completely modular and allow for quick exchange of any of its major blocks.

The infrared sensor brick which is based on the concept of modular sensor bricks would consist of an acquisition (sensor) block to capture images, a processing and fusion block to work on the acquired images, a communication block for transferring data between the sensor brick and the host computer located either on the robot or somewhere remotely, and a power block to maintain power supply to the whole brick. The infrared sensor brick would be a self-sufficient system and it would be possible to remove it from the robot and attach it back at any desired time without affecting the main setup of the robot. The brick could also exist as a stand alone system to capture infrared data and transmit it for useful purposes. We will also acquire some thermal under vehicle video sequences using this thermal sensor brick. These sequences will be obtained to observe variations in under vehicle conditions with respect to time, and to display the advantages of the thermal camera in detecting hidden objects, which may be possible threat objects and may remain occluded on a visual image. We will also develop a GUI for the thermal sensor brick; which will help us in data acquisition and in performing some processing operations on the acquired thermal data.

All in all the objective of this project is to actually build an infrared imaging sensor brick as per our own design and to test it. The brick would have several applications which could include motion detection and intrusion detection, face recognition, pattern recognition, under vehicle surveillance, general area surveillance and others.

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1. Introduction

The infrared imaging sensor brick for modular robotics that has been implemented by us has been both designed and built with main focus being set on its modularity and self-sufficiency. Since the sensor brick that has been built is a highly modular system; such a setup allows us to replace almost each and every major component in the system without affecting the remaining setup. This sensor brick which is like a plug and play device can thus exist either as a stand-alone system or as part of a multi sensor modular robotic setup. The sensor brick consists of an infrared sensor (Omega infrared camera now known as the ThermoVision Micron manufactured by Indigo systems) for acquiring data or images, a video capture (frame grabber) card connected to the CPU from the camera helps in analog data capture. Toshiba Satellite Notebook A10-S129, which is a 2.4 GHz Celeron notebook computer manufactured by Toshiba Inc., has been used as the CPU on the sensor brick. Here is where some elementary image processing operations are performed on the acquired images. The communication between the brick CPU and the host computer has been setup using 802.11g standard USB based W-LAN network adapter card connected to the CPU. Lastly the power block, which provides for the entire power supply requirements of the brick, consists of a 12V battery, a 12V, 100W – 15V, 75W dc-to-dc converter to power the laptop (CPU) and a 12V – 5V dc-to-dc converter to power the camera.

1.1. Motivation and Overview

The infrared sensor brick promises to be of great use in search and surveillance operations with its inherent advantages being that it is small in size and light in weight. Being able to capture infrared data is what makes it very special because in the dark where human vision stops the infrared sensor could be used to detect possible ambushes, plots and hidden enemies by making use of its night vision capabilities. The thermal images generated could also be used for human detection and intrusion detection, face recognition, pattern recognition, human tracking and in very many applications of thermal imaging. Since currently the increase in the level of concern for both safety and security issues has no bound, this was the main motivating factor for taking up this project.

Many robot based image processing systems are currently available for both commercial and research operations. The robotic systems which are available are usually fitted with only one or two kinds of sensors (mostly cameras). The systems available are generally neither light in weight nor small in size and in case if any system is small in size and light in weight then it is highly improbable to be as highly sophisticated and modular as our sensor brick system. Amongst the commercially available robots the Mini – Andros can be fitted with an infrared camera [1], the Spiral Track Autonomous Robot (STAR) can be equipped with infrared sensors [1] but this might not be a camera. Another very popular commercial robot the Robug III cannot be equipped with infrared cameras [1].

The above discussion helps us to a certain extent in getting a clearer picture about the possible advantages of our sensor brick. Infrared imaging based robotic systems have been used previously in high-level rescue operations like in the case of rescue operation at the world trade center site [3]. The robots used there were equipped with infrared cameras so that the body heat could be detected very easily [3]. Robotic systems with infrared cameras have also been used to recover flight recorders of electronic aircraft data and voice recordings [3]. So all in all, we know that the infrared sensor brick would be an important arm of any modular robotic platform meant for search and surveillance since it would help in giving vision beyond the human eyes and thereby help in overcoming the loopholes left in search and surveillance operations due to the limitations of a vision camera.

1.2. Mission and Applications

The conceptual diagram of the modular infrared imaging sensor brick system that has been developed by us is as shown in Figure 1.1 below. The infrared sensor brick consists of 4 main blocks, it has an infrared sensor (Omega infrared camera now known as the ThermoVision Micron manufactured by Indigo systems) for the acquisition of thermal data or images. It has an Imperx VCE PRO video capture (frame grabber) card connected to the CPU which helps in analog data capture. These two components make up the sensing and image acquisition block. Toshiba Satellite Notebook A10-S129 which is a 2.4 GHz Celeron notebook computer manufactured by Toshiba Inc. has been used as the CPU on the sensor brick. Here is where some elementary image processing operations are being performed on acquired images. This part of the sensor is the processing and fusion block of the sensor brick. The communication between the brick CPU and the host computer has been setup using Linksys WUSB54G 802.11g standard USB based W-LAN network adapter card which is connected to the CPU. This is the communication block of the sensor brick. The Power block, which provides for the entire power supply requirements of the brick, consists of a 12V Panasonic battery LC – RA1212P and a 12V, 100W – 15V, 75W dc-to-dc converter manufactured by Vicor Corporation that powers the laptop (CPU) and a 12V – 5V dc-to-dc converter manufactured by V-infinity to power the camera.

We conducted a brief survey before selecting the infrared camera for our sensor brick and the main parameters that we considered were less weight, small size and low power requirements. All the cameras considered were those in which the detectors were Focal Plane Array - (FPA) uncooled microbolometer type. Seen in Table 1.1 below is a brief comparison of all the cameras considered, based on the parameters defined by our needs. All the cameras considered did not exhibit the zooming feature and also required manual adjustment of focus since they were not equipped with auto focus.

From the table below it is clear that the infrared camera that was best suited for our thermal sensor brick was the Omega infrared camera manufactured by Indigo Systems Corporation, since it proved to be the best on all the parameters that we had set for our selection. Omega is the lightest, smallest, consumes the least amount of power and has a good temperature range. Also the camera comes in with an accessory of lenses of three different wavelengths.

SENSOR BLOCK	PROCESSING AND FUSION BLOCK	COMMUNICATION BLOCK
(The Omega infrared camera, now known as the ThermoVision Micron.)	(Simple image processing operations on acquired images)	(Use 802.11g standard USB based W-LAN network adapter card to communicate with the host computer)
POWER BLOCK (12V battery supply , 12V,100W – 15V, 75W dc to dc converter for the Laptop and a 12V – 5V dc to dc converter for the camera)		

Figure 1.1 Conceptual diagram of the self-sufficient thermal sensor brick system implemented by us that is like a plug and play device.

Comparison of different types of infrared cameras

Infrared Camera	Field of view/ min focus distance	Spectral range	Weight	Dimensions	Volume	Power required	Temperature range
UL3 Alpha	(25°×19°/0.3m)	8 – 12 µm	< 200g	1.7”×1.7”×3.0”	8.67 cubic in	≤ 1.5 W	0°C to +55°C
Omega	11mm - (40°×30°/0.1m) 18mm – (25°×19°/0.3m) 30mm – (15°×11°/0.3m)	7.5–13.5 µm	< 115g	1.4”×1.3”×1.9”	3.46 cubic in	≤ 1.1 W	-40°C to +55°C
ThermaCAM E2	(25°×19°/0.3m)	7.5 – 13 µm	< 700g	10.4”×3.2”×4.1”	136.45 cubic in	≤ 6 W	-15°C to +45°C
ThermaCAM E4	(25°×19°/0.3m)	7.5 – 13 µm	< 700g	10.4”×3.2”×4.1”	136.45 cubic in	≤ 6 W	-15°C to +45°C

Table 1.1 A comparison of different cameras considered in our survey.

With extra impetus being given to security and safety issues in the past two years the infrared sensor brick has many applications especially in search and surveillance operations. When hooked up to a bigger system like a modular robotic platform the infrared imager could give the robot night vision to control its movement in the dark [8]. The thermal images could also be used to thwart ambushes and plots laid in the dark by people directly or by using other objects or animals [8]. Other primary applications of the sensor brick could be in face recognition, pattern recognition and also perhaps in human tracking systems [8]. Most of the above-mentioned applications of the sensor brick would be of use in military operations. The other possible applications of the sensor brick could be in industrial production for quality control in the manufacturing process of a variety of products ranging from food items, glass, cast iron patterns, moulds and others where quality assurance of the product and surveillance on the production line is a necessity [8]. The sensor brick could also be setup to guard secure locations where it would be expected to monitor entry and exit to a particular room or building by allowing only selected people; it would accomplish this by using face recognition by thermal images to match new images with its current database [8].

When setup on a robotic chassis the sensor brick could possibly help in scouting missions like in a building or in a nuclear reactor where it could be asked to detect leaks, fire, see through smoke and search for victims, detect for the presence of other flammable substances [2]. On a larger scale the applications could include but not be limited by area surveillance, checking for wanted suspects using face detection, in naval operations it could be used for detecting possible oil spillage and also threat from enemy vessels at night in the dark [2]. In air force they could use it for aerial surveillance and enemy detection. Some of the commercial applications would include coverage of disaster footages through smoke and dark areas, traffic reports even on a rainy and foggy day [2].

The applications that we have focused on are under vehicle inspection by mounting the infrared imaging sensor brick on the tracked under vehicle robot and human tracking to guard a secure location by setting the brick in an area that needs to be guarded against intrusion.

2. Implementation of the Thermal Sensor Brick

In this section we shall be dealing in detail with the four blocks of the sensor brick that have been implemented in building the thermal sensor brick system. The first and the most important block of the sensor brick that we need to look at is the Sensing and Image Acquisition block. Here is where we undergo the process of image acquisition using the thermal camera and analog data capture using the video capture card. The second block of the sensor brick that we shall deal with is the Processing and Fusion block. In this block we shall look at the preprocessing operations that are performed on the acquired images. The third block is the communication block which basically deals with the 802.11g W LAN setup for the transfer of data between the host computer and the brick CPU. Lastly we shall look at the power block of the sensor brick which deals with the power setup for running the camera and the CPU. All these blocks which are being discussed here have actually been implemented and tested. The infrared imaging sensor brick has been built on the design as shown in Table 2.1 below.

Sensing and Image Acquisition B1ock.	**Preprocessing and Fusion Block.**	**Communication Block.**	**Power Block.**
Sensor: (Omega infrared camera, now known as ThermoVision Micron). ***Frame Grabber:*** IMPERX VCE-PRO Fast Analog CardBus video capture (frame grabber) card.	***CPU:*** 2.4 GHz Celeron, Toshiba Satellite A10-S129 Notebook computer.	***Wireless Card:*** Linksys WUSB54G (a USB based 802.11g standard W-LAN network adapter card). It has a 100 – 150 feet coverage area inside a room.	***Battery:*** Panasonic LC – RA1212P a 12V battery. 12V, 100W – 15V, 75W dc-to-dc converter manufactured by Vicor Corporation that powers the laptop (CPU). 12V – 5V dc-to-dc converter manufactured by V-infinity to power the camera.

Table 2.1 The hardware architecture of the infrared imaging sensor brick implemented by us.

2.1. Sensing and Image Acquisition Block

The first and the most important block of the sensor brick that we need to deal with is the Sensing and Image Acquisition block. On our sensor brick we have an infrared sensor (the Omega infrared camera now known as ThermoVision Micron) to capture infrared images. The Omega infrared camera is the world's smallest and lightest infrared camera. This camera was developed in 2002 as part of a joint venture program between Night Vision and Electronic Sensors Directorate NVESD (a US army – communications command research and development center) and Indigo Systems Corporation of Santa Barbara CA. The Omega belongs to the UL3 family of infrared cameras manufactured by Indigo systems [5].

The Omega is a commercial off-the shelf (COTS) thermal imager and has features like being the smallest in size (3.5 cubic inches), lightest in weight (102 grams) and has a very low power consumption (< 1.3 W) [Kostrzewa-I]. It employs a 164 X 120 uncooled microbolometer focal plane array (FPA) and is extremely well suited for applications like security, search and remote surveillance, miniature unmanned aerial vehicles (UAV's), weapon sights, checking mine fields and in unattended ground sensors (UGS) [Kostrzewa-I]. It finds applications for military purposes like unattended networked sensor guarding of points as in our case by a modular unmanned robot; commercial applications like in checking for hot spots and seeing through smoke in fire fighting applications [Kostrzewa-I].

2.1.1. Omega Infrared Camera

The Omega is a long-wavelength thermal camera with sensitivity in the range of 7.5 microns – 13.5 microns. Small size, light weight and low power consumption which are the key features of the Omega camera are all achieved by employing state of the art readout integrated circuit (ROIC) design and innovative electronics packaging concepts [Kostrzewa-I]. Figure 2.1 below shows a picture of the omega infrared camera.

Figure 2.1 The Omega infrared camera. This picture has been obtained from the official website of Indigo Systems Corporation.

The Omega camera does not have a Thermoelectric Cooler (TEC), which is usually found in most uncooled cameras. The TEC helps in maintaining the focal plane array

(FPA) at a stable temperature else their output would vary non-uniformly, causing undesirable image artifacts. The Omega instead utilizes a completely new technique by combining on-focal-plane circuitry and NUC (non uniformity correction) processing to eliminate the use of TEC. This helps the camera to operate over a wider temperature range while at the same time maintaining its dynamic range and image uniformity [Kostrzewa-II].

These above mentioned design features of the Omega are those which are mainly responsible for the small size, light weight, low power consumption and low costs. The absence of a TEC helps in reducing the complexity of the camera, thereby giving it a higher range of operation and also instant imaging on turn on in comparison to those cameras employing FPA temperature stabilization with a TEC which usually have a long enough waiting time [Kostrzewa-II].

Seen given in Table 2.2 below are the specifications and the technical details of the Omega infrared camera. These specifications have been obtained from the official website of Indigo Systems Corporation [5].

Detector type	Uncooled microbolometer
Array format	160 H X 120 V (RS 170 - A display); 160 H X 128 V (CCIR display)
Pixel size	51 X 51 microns.
Optical still factor	65%
Spectral response	7.5 - 13.5 microns.
Thermal stabilization	Not required.
Calibration source	Internally located in camera (offset only).
Video output	RS 170 - A display; optional CCIR display.
Frame rate	30 Hz RS 170 – A; 25 Hz CCIR.
NedT factor	< 85mK (equivalent to 49mK at f/1.0).
Operability	> 98%
Time to image	2 seconds max.
Cooling method	Conduction to camera bottom.
Mounting interface	1 helicoil insert in camera base, guide-pin hole.
Dimensions	1.35”W X 1.45”H X 1.90”D without lens.
Weight	< 120g, lens dependent.
Power	< 1.5 W (nominal).

Input/Output	18-pin connector for video, power, communication, digital data.
Serial commands	RS-232 interface
Digital data *	Optional real time, 14-bit, pixel replaced, normalized digital output.
Operating temperature range *	0°C to + 40°C standard; and an optional – 40°C to +55°C extended temperature range.
Scene temperature range *	To 150°C standard; and an optional auto-gain mode range to 400°C.
Humidity	95% non-condensing.
Optics material	Germanium
f-number	1.6
Lens focal lengths	11mm, 18mm, 30mm.
Field of view (degrees)	(40 X 30), (25 X 19) and (15 X 11) respectively.
IFoV (milliradians)	4.64, 2.83, 1.70 respectively.

Table 2.2 Technical specifications and additional features of the Omega infrared camera.

* These features are extra and so are additional and are not part of regular accessories.

Some of the major advantages that the Omega camera presents over other infrared cameras are that:

- The Omega is extremely compact, light in weight and has a fully integrated design. This has been achieved by the manufacturer by being successful in producing Vanadium oxide VOx microbolometer detectors along with proprietary on-focal-plane signal processing that helps in obtaining extraordinary image quality and a high level of image resolution [5].
- Since the design of the camera makes a total move away from one traditionally based on thermoelectric (TE) stabilization this is what allows the camera to operate with extremely low power consumption and also allows it to display the first image in less than 2 seconds. The camera also incorporates analog RS 170 – A as well as 14-bit digital output [5].

The Omega which is the world's smallest thermal camera is as good as a larger infrared camera with regards to its performance and features that it has got to offer. The Omega which has a 160 X 128 focal plane array with signal processing, DSP based electronics and real time algorithms can deliver image quality as good as larger arrays

[5]. This proves that it basically makes no compromises for its small size [5]. The VOx detectors allow the Omega to use a higher f-number optics thereby helping in reducing costs and weight [5]. While using the standard f/1.6 lens, it can give a NedT of < 80mK, whereas while using an optional f/1.0 lens, this comes down to < 40mK – which is a factor of 3 better than other competing technologies [5]. Figure 2.2 below shows the 3 different lenses that can be fitted on the omega camera.

Figure 2.2 The 3 lenses (11mm, 18mm and 30mm) that are part of the optional accessories for the Omega camera. This picture has been obtained from the official website of Indigo Systems Corporation.

The Omega has both an analog and a digital output. It is also capable of delivering wide dynamic range (14-bit) images at real-time video rates (30 fps) for RS 170 – A or (25 fps) for CCIR [5]. A function in the Omega called auto-ranging spots out extremely hot scenes and decides to switch into an extended temperature range mode thereby allowing to image scenes up to 400°C [5]. There is an internal shutter that continuously recalibrates the camera automatically or can be manually overridden. This helps in process monitoring applications [5]. The analog video output utilizes a feature called *"Smart Scene"* which helps to enhance picture quality for all the scenes. This feature uses a dynamic, non-linear conversion to process the 14-bit digital image data into 8-bit data for analog video [5]. The conversion algorithm automatically adjusts, frame by frame, to maximize the contrast in darker (colder) parts of the frame, while trying to avoid blanking of brighter (hotter) objects in the image frame. The advantage of this feature is that we automatically get a continuously optimized image which is independent of scene dynamics [5].

The camera also comes in with a proprietary image optimization system that pre-processes the image data, and eliminates the need for temperature stabilization of the array [5]. This helps in operating over a wider temperature range. Hence the system does not need a thermoelectric cooler and this helps in saving on the power consumption [5]. The absence of a TE cooler also helps in giving a very fast turn on time which is highly advantageous [5].

2.1.2. Imperx VCE PRO Frame Grabber (video capture) card

After having dealt with the infrared sensor the Omega infrared camera the other equally important component of this block that we need to look at is the video capture (frame grabber) card. The video capture card that we have fitted to the CPU on our system is IMPERX VCE-PRO Fast Analog CardBus video capture card manufactured by Imperx Inc [6]. This video capture card is necessary for capturing analog video sequences directly from the Omega infrared camera. The IMPERX VCE-PRO is a PCMCIA based video capture card and is inserted in the PCMCIA slot on the CPU. An S-Video to RCA adapter cable is used to connect the Omega camera and the frame grabber card. The video capture card thus helps us in grabbing live streaming video captured by the camera. The card comes in with its own graphical user interface (GUI) which helps us in controlling all its operations.

The VCE-PRO offers us a high performance full frame capture PC CardBus 8.0 based capture card [6]. This card is perfectly suited to our design since it is like a plug and play device with hot insertion and removal so this means that we need not have it on the CPU at all times but we can use it whenever we want or else have it taken off. It is capable of displaying, capturing, storing and previewing full motion video (i.e.) 30 frames per second at full - VGA or higher resolution [6]. It also gives us the option of being able to capture only one frame, multiple frames, and also standard (.avi) format video clips from NTSC, PAL or SECAM sources [6]. The VCE-PRO video capture card comes in with an inbuilt capture delay function which allows users to program the card so that video sequences scheduled at a later date can be recorded [6]. The card comes in with an external trigger option which makes it very useful in certain demanding machine vision applications [6]. The Imperx VCE-PRO video capture card is as shown in Figure 2.3 below.

Figure 2.3 The IMPERX VCE PRO Fast Analog CardBus video capture (frame grabber) card. This picture has been taken from the official website of Imperx Inc.

Seen given in Table 2.3 below are the technical specifications of the IMPERX VCE-PRO Fast Analog CardBus video capture card. All these specifications have been obtained from the official website of Imperx Inc. [6].

Input	2 – Composite inputs or 2 – S Video inputs with anti alias filters. 1 – External trigger input.
Fast video capture window frame sizes	640 X 480 pixels @ 30 fps. 320 X 240 pixels @ 30 fps. 160 X 120 pixels @ 30 fps.
Image controls	Adjustable image brightness, contrast, saturation and hue.
Image formats	24 bit RGB image or gray scale image; and 8 bit gray scale image.
Frame capture	Single frame, Multiple frame and Standard (.avi) clips.
Video source	Composite or S Video
Dimensions	PCMCIA Type II: 85mm(3.3 in) X 54mm(2.1 in) X 5mm(0.2 in)
Weight	35 grams (1.25 oz).
Operating voltage Operating current Inrush current	3.3 V +/- 5%. 160 mA. 350 mA.
Operating temperature	0°C - 65°C.
Relative humidity	90% non-condensing.
Operating system	Windows 2000 and XP.
Additional features	Adjustable frame rates. Programmable date and time recording and capture delay of up to 60 minutes. BMP and adjustable JPEG file formats. Automatic NTSC/PAL format detection and automatic gain control. 16 bit YCrCb (4:2:2) digital output.

Table 2.3 Technical specifications of IMPERX VCE - PRO Fast Analog CardBus video capture (frame grabber) card.

2.2. Processing and Fusion Block

After having seen the Sensing and Image Acquisition block of the sensor brick the next block that we need to deal with is the Processing and Fusion block. Here (i.e. in the CPU) the data acquired by the sensor using the analog capture card fitted on the CPU would be captured and some low-level image processing operations would be done on these captured images. This is all the processing that is done at the level of the sensor brick and the processed images are available to the remotely located host computer for further use.

2.2.1. Central Processing Unit

This is where the images captured by the Omega infrared camera would be obtained, stored, processed and transmitted. The CPU is Toshiba Satellite Notebook A10-S129 Celeron 2.4G, 15"TFT, 256MB, 40GB, DVD/CDRW, 56K, LAN, WinXP Pro. This is a notebook computer manufactured by Toshiba [7]. All the below mentioned specifications of the Toshiba Satellite Notebook A10-S129 have been obtained from Newegg.com official website. The Toshiba Satellite Notebook computer is as shown in Figure 2.4 below.

- **Model Number:** Toshiba Satellite A10-S129 (PSA10U-0ZH6M7).
- **Processor:** Intel Celeron 2.4 GHz (400 FSB, 256KB L2 Cache).
- **Chipsets:** Intel 852GM.
- **Display:** 15"TFT (1024 x 768 @ 24bit).
- **Operating System:** Microsoft Windows XP Professional.
- **Graphics:** Intel 852GM integrated graphics controller; 32MB shared memory external and a maximum resolution of up to 1920 x 1440.
- **User Interface:** Full sized 85 keys with 12 function keys keyboard touchpad.
- **Sound:** Analog Devices AD1981 Codec Chip; Software Sound; Sound Blaster Pro Compatibility.
  Ports: external microphone port, headphone port, line-in port.
- **Memory:** 1 x 256MB (2 x 184 pin) DDR (Max. capacity 1GB).
- **PC Card Slot:** Supports 1x Type II PC Card.
- **USB:** 2 x USB2.0.

- **Others:**
    - 1 x RJ - 45 LAN port.
    - 1 x Parallel Port.
    - 1 x VGA Port.
    - 1 x RJ - 11 Modem port.

- **Dimension:** 13.0” (L) x 11.5” (W) x 1.5” (H) inches.

- **Weight:** 6.3 lbs.

- **AC Adapter:** 75W external AC Adapter, 100-240V / 50-60Hz frequency (Universal) input voltage, 15V x 4A output.

- **Battery Type:** 6-cell, rechargeable, removable Lithium Ion (Li-Ion) battery, 4400mAh.

- **Average Battery Life:** Approx 3.22hour(s).

- **RAM:** Original 256 MB RAM + extended 512MB RAM = Total 768MB RAM.

- **Hard Disk:** 40 GB (4200 RPM).

- **Optical Driver:**
  DVD/CD-RW combo driver.
    - DVD-ROM read speed: 8x.
    - CD-ROM read speed: 24x.
    - CD write speed: 24x.
    - CD rewrite speed: 10x.

Figure 2.4 Different views of the Toshiba Satellite A10 - S129 Notebook computer. This has been used as the CPU on our thermal sensor brick system. These pictures have been obtained from NewEgg.com.

2.3. Communication Block

After having dealt with the Processing and Fusion block of the sensor brick the next block that we need to deal with is the Communication block. This section of the sensor brick deals with communication between the brick CPU and the host computer situated far away from the sensor brick. For transmitting this acquired as well as preprocessed data to the host computer or to the server so that it is available for further use and interpretation to users located far away from the sensor brick we are employing a USB based 802.11g W - LAN network adapter card. The 802.11g Wireless LAN network adapter card that we have used on our sensor brick is Linksys WUSB54G. This is fitted to the USB port on the CPU. The environments in which we anticipate our brick might have to be placed in while perhaps on a search or surveillance mission forced us to go in for the slower but yet highly versatile W-LAN setup using the 802.11g wireless standard.

Section that follows takes a closer look at some of the details of the 802.11g W – LAN standard in general and some specifications about the W-LAN network adapter card used on our sensor brick: - The 802.11g has a 54Mbps data rate and is reverse compatible with the 802.11b standard [18]. The modulation technique used in 802.11g standard is called the Orthogonal Frequency Division Multiplexing (OFDM) which is similar to the one used in 802.11a. This is what is mainly responsible for the higher data rates achievable with 802.11g [8]. The operation of 802.11g in the 2.4GHz band and the modulation technique of Complementary Code Keying (CCK) is what makes it similar to the 802.11b and so the 802.11g is reverse compatible with the 802.11b [8]. The 802.11g like the 802.11b has only three non-overlapping channels and hence suffers from interference from other circuits like cordless phones and microwave ovens which also operate in the 2.4 GHz range [8].

- The 802.11g can achieve a maximum speed of 54 Mbps which is as much as the 802.11a and 5 times more then the 802.11b [18].

- The 802.11g like the 802.11b has a coverage area of 100–150 feet inside a room depending on the materials used in the walls as well as the layout of the room, while the 802.11a has a coverage area of only about 25 –75 feet indoors [18].

- Since the 802.11g is reverse compatible with the 802.11b which is a widely used highly compatible system the 802.11g has all its features of public access [18].

- The 802.11b is the most widely adopted and hence an inexpensive technology, but the 802.11g being new is not that widespread. It is also relatively inexpensive if we weigh the cost against the benefits it has to offer [18].

- The only possible disadvantage of the 802.11g like the 802.11b is that it operates in the crowded 2.4 GHz range which runs it a high risk of interference. On the other hand the 802.11a operates in the uncrowded 5.7 GHz range and so can coexist with 2.4 GHz range circuits without any interference [18].

Figure 2.5 WUSB54G an 802.11g standard USB based W - LAN network adapter card. This picture has been taken from the official website of Linksys Inc.

Figure 2.5 above shows a picture of the WUSB54G network adapter card. Given in Table 2.4 [18] below are the technical specifications of Linksys WUSB54G 802.11g standard USB based W-LAN network adapter card. All these specifications have been obtained from the official website of Linksys Inc. [18].

Standards	IEEE 802.11b, IEEE 802.11g; USB1.1 and USB 2.0.
Port	USB port.
Channels	802.11b/ 802.11g (11 channels).
LED’s	Power and link.
Transmitted power	15 - 17dBm (typical) @ 11M CCK; 13 - 15dBm (typical) @ 54M OFDM.
Receive sensitivity	54Mbps @ -65dBm, 11Mbps @ -80dBm.
Antenna	2dBi.
Security features	WEP encryption.
WEP key bits	64, 128 bit.
Dimensions	3.58” X 0.91” X 2.80”.
Weight	0.18 lbs (0.08 kg).
Operating temp.	32°F to 104°F (0°C to 40°C)
Storage temp.	-40°F to 185°F (0°C to 70°C)
Operating humidity	10% to 85% non-condensing.
Storage humidity	5% to 90% non-condensing.
System requirements	PC with 400 MHz or faster processor; 64 MB RAM; CD – ROM Driver; Available USB port and Windows 2000 or XP operating system.

Table 2.4 Technical specifications of the Linksys WUSB54G W - LAN network adapter card.

2.4. Power Block

After having dealt with the Communication block of the sensor brick the next and final block that we need to deal with is the Power block. Power supply is the most important factor for continuous and stable operation of the sensor brick. Since we know that the sensor brick which has been designed on the concept of modularity and self sufficiency would exist either as a stand alone system or as part of a modular robotic system this would mean that it would require its own power setup at all times.

This block of the thermal sensor brick deals with the supply of power to all the individual blocks of the sensor brick. The power block, which provides for the entire power supply requirements of the brick necessary for continuous stable operation, consists of a 12V Panasonic battery LC – RA1212P and a 12V, 100W – 15V, 75W dc-to-dc converter manufactured by Vicor Corporation that powers the laptop (CPU) and a 12V – 5V dc-to-dc converter manufactured by V-infinity to power the camera. The 12V Panasonic battery LC – RA1212P is as shown in Figure 2.6 below and its technical specifications are given in Table 2.5 below. They are obtained from Panasonic's official website [19].

Figure 2.6 The 12V battery Panasonic LC - RA 1212P. This picture has been obtained from the Panasonic website.

Nominal Voltage.	12V.
Nominal capacity (20hr rate)	12Ah.
Dimensions (in inch)	Total height: 4.01 inch (102 mm). Height: 3.70 inch (94 mm). Length: 5.95 inch (151mm). Width: 3.86 inch (98mm).
Weight	8.41 lbs (3.8 Kgs).

Table 2.5 Technical specifications of the 12V Panasonic battery, LC - RA 1212P.

VI-200 the 12V, 100W – 15V, 75W dc-to-dc converter manufactured by Vicor Corporation that powers the laptop (CPU) is as shown in Figure 2.7 below and its technical specifications are given in Table 2.6 below. These specifications have been obtained from the official website of Vicor Corporation [20].

Figure 2.7 12V, 100W - 15V, 75W dc to dc converter VI - 200. This picture has been obtained from the official website of Vicor corporation.

Input voltage	12V.
Output voltage	15V.
Output power	75W.
Dimensions	4.6” X 2.4” X 0.5” (116.9 mm X 61.0 mm X 12.7 mm).
Weight	6.0 oz / 170g.
Efficiency	Up to 90%.

Table 2.6 Technical specifications of VI - 200 a 12V, 100W - 15V, 75W dc to dc converter manufactured by Vicor corporation.

Figure 2.8 12V to 5V dc to dc converter VAS1R5-S5-S. This picture has been obtained from the official website of V - infinity.

VAS1R5-S5-S series 12V – 5V dc-to-dc converter manufactured by V-infinity which is used to power the camera is as shown in Figure 2.8 above and its technical specifications are given in Table 2.7 below. These specifications have been obtained from the official website of V – Infinity [21].

Input voltage	12V.
Output voltage	5V.
Output power	1.5W.
Dimensions	1.25” X 0.8” X 0.4” (116.9 mm X 61.0 mm X 12.7 mm).
Efficiency	50%.

Table 2.7 Technical specifications of 12V - 5V dc to dc converter manufactured by V - infinity.

3. Architecture

As is clear from the above sections, the sensor brick consists of four major blocks. Firstly the sensing and image acquisition block which mainly consists of the sensor, the Omega infrared camera and the frame grabber (video capture) card on the CPU to obtain live analog data. Second is the processing and fusion block, here (i.e. in the CPU) is where the data acquired by the sensor would be operated on and some basic pre- processing of thermal data done through use of software. Thirdly comes the communication block for transmitting this acquired and processed data to the host computer or to the server so that it is available for further use and interpretation by users located far away from the sensor brick. Finally comes the power block which manages the power supply for each and every block of the sensor brick for continuous and steady operation of the sensor brick components.

In this section we shall deal with both the hardware and the software architecture of the infrared imaging sensor brick. We shall firstly take a look at the progression of the thermal sensor brick design, and then look in detail at the packaging of the thermal sensor brick that has been built by us as part of the hardware architecture. Secondly we shall deal with the software architecture which would give us the details of all the software's that would help in acquiring images. We shall discuss the GUI that came along with the Imperx VCE Pro frame grabber card and the GUI that has been developed by us for the sensor brick system and the on brick processing operations that have been incorporated into the GUI.

3.1. Packaging and Hardware Architecture

The hardware architecture of the infrared imaging sensor brick that has been implemented by us is as given below:-

Sensing and Image Acquisition block: - This section of the sensor brick consists of the infrared sensor for capture of thermal data and the video capture (frame grabber) card which allows us to perform analog video capture of data on the sensor brick.

Processing and Fusion block: - This section of the sensor brick is where the processing and fusion of acquired thermal images takes place. Here (i.e. in the CPU) is where the data acquired by the sensor through analog capture card fitted on the CPU would be operated on and some basic pre- processing of thermal data done through use of software. The CPU is Toshiba Satellite Notebook A10-S129 Celeron 2.4G, 15"TFT, 256MB, 40GB, DVD/CDRW, 56K, LAN, WinXP Pro. This is a notebook computer manufactured by Toshiba Inc [7].

Communication block: - This section of the sensor brick deals with communication between the brick CPU and the host computer situated far away from the sensor brick. For transmitting this acquired and preprocessed data to the host computer or to the server so that it is available for further use and interpretation to users located far away from the sensor brick we are employing a USB based 802.11g W - LAN network adapter card. The 802.11g wireless LAN network adapter card that we have used on our sensor brick is

Linksys WUSB54G and it is fitted to the USB port on the CPU.

Power block: - This section of the sensor brick deals with the management of power supply to all the blocks of the sensor brick for its continuous and stable operation. Here we have Panasonic LC – RA1212P a 12V battery that powers the entire brick. We also have a 12V - 15V dc to dc converter VI – 200 manufactured by Vicor Corporation to power the CPU (laptop) and a 12V - 5V dc to dc converter VAS1R5-S5-S series manufactured by V – Infinity to power the camera.

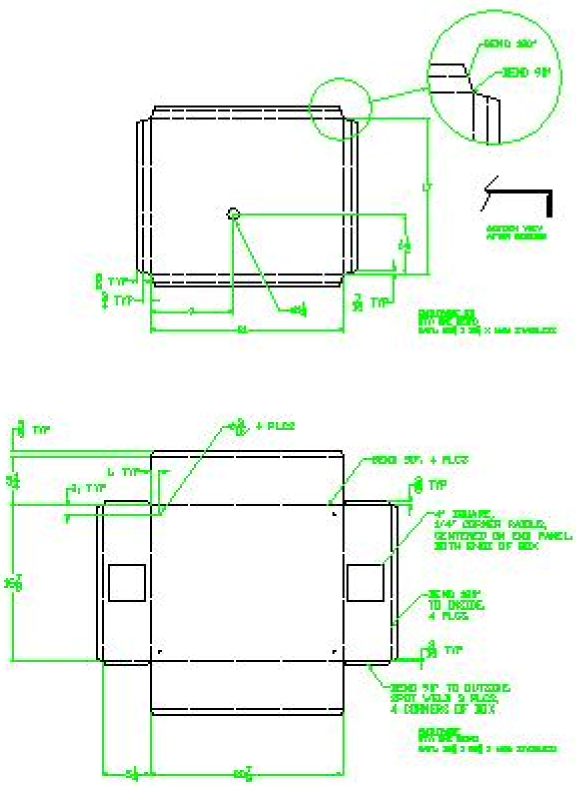


Figure 3.1 Design of the outer aluminum box built by us for the thermal sensor brick. Design courtesy Doug Warren.

The infrared imaging sensor brick has been packaged by housing it in a 21” x 17” x 5.25” dimension box of aluminum built by us for it. The thermal sensor brick has been designed and built based on the concept of modular sensor bricks. The brick has a single ON/OFF switch, and operates on power drawn from one single 12V battery source. The package is also robust enough to be both airline and land travel compatible. The design of the brick is completely modular and allows for quick exchange of any of its major blocks. The design of the outer box for the thermal sensor brick is as shown in Figure 3.1 above. This work was done in co-ordination with Doug Warren who helped by guiding me in planning and executing all the sheet metal work. He provided useful inputs for making the box and also contributed towards making it.

3.1.1. Progression of the thermal sensor brick design

On our infrared imaging sensor brick we have an infrared sensor (Omega infrared camera now known as the ThermoVision Micron) for the acquisition of thermal data or images. It has an Imperx VCE PRO video capture (frame grabber) card connected to the CPU, which helps in analog data capture. These two components make up the sensing and image acquisition block. Toshiba Satellite Notebook A10-S129, which is a 2.4 GHz Celeron notebook computer manufactured by Toshiba Inc., has been used as the CPU on the sensor brick. This part of the sensor brick is the processing and fusion block. The communication between the brick CPU and the host computer has been setup using Linksys WUSB54G 802.11g standard USB based W-LAN network adapter card, which is connected to the CPU. This is the communication block of the CPU.

Some changes have been inflicted in the power block of the thermal sensor brick and this is what has led to the evolution of the brick design. Earlier the camera used to power itself using its own battery pack and the CPU had its own battery setup. These two battery setups would make up the power block, which would provide power supply to all the brick components. Now the power block, which provides for the entire power supply requirements of the brick, consists of a 12V Panasonic battery LC – RA1212P and a 12V, 100W – 15V, 75W dc-to-dc converter manufactured by Vicor Corporation that powers the laptop (CPU) and a 12V – 5V dc-to-dc converter manufactured by V-infinity to power the camera. Figure 3.2 below shows the previous component wise diagram of the thermal sensor brick and Figure 3.3 shows the current component wise diagram of the thermal sensor brick.

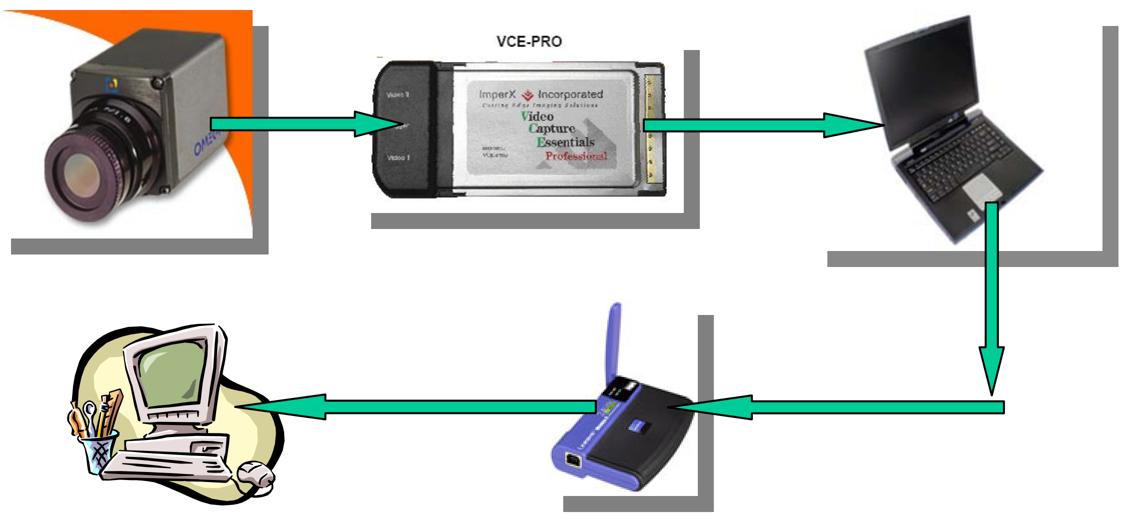


Figure 3.2 Original component wise diagram.

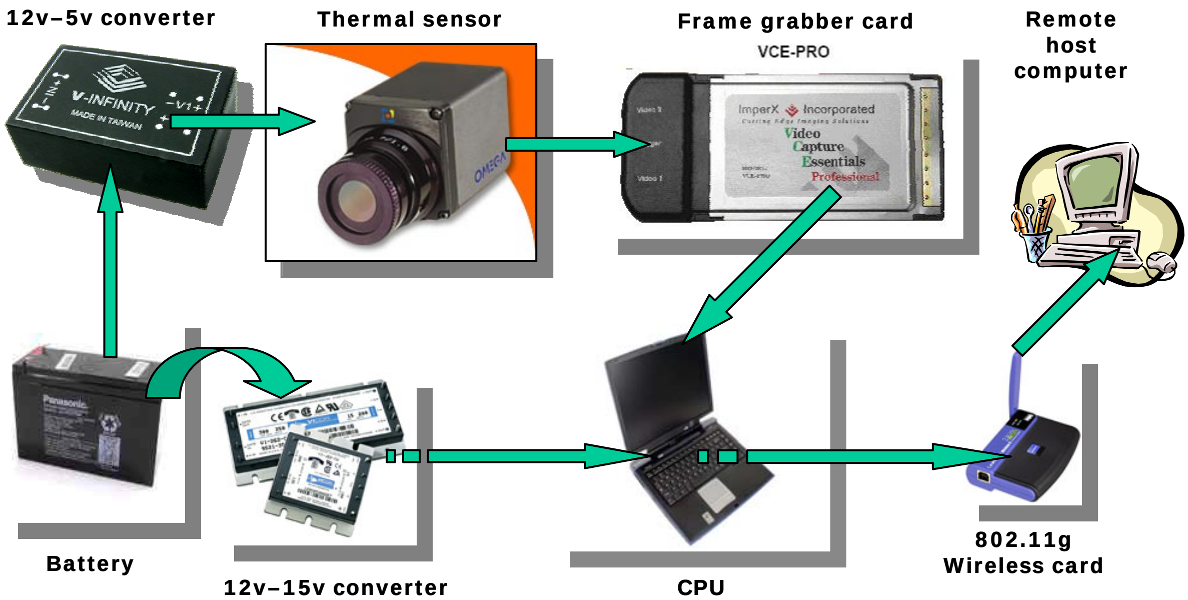


Figure 3.3 Current component wise diagram.

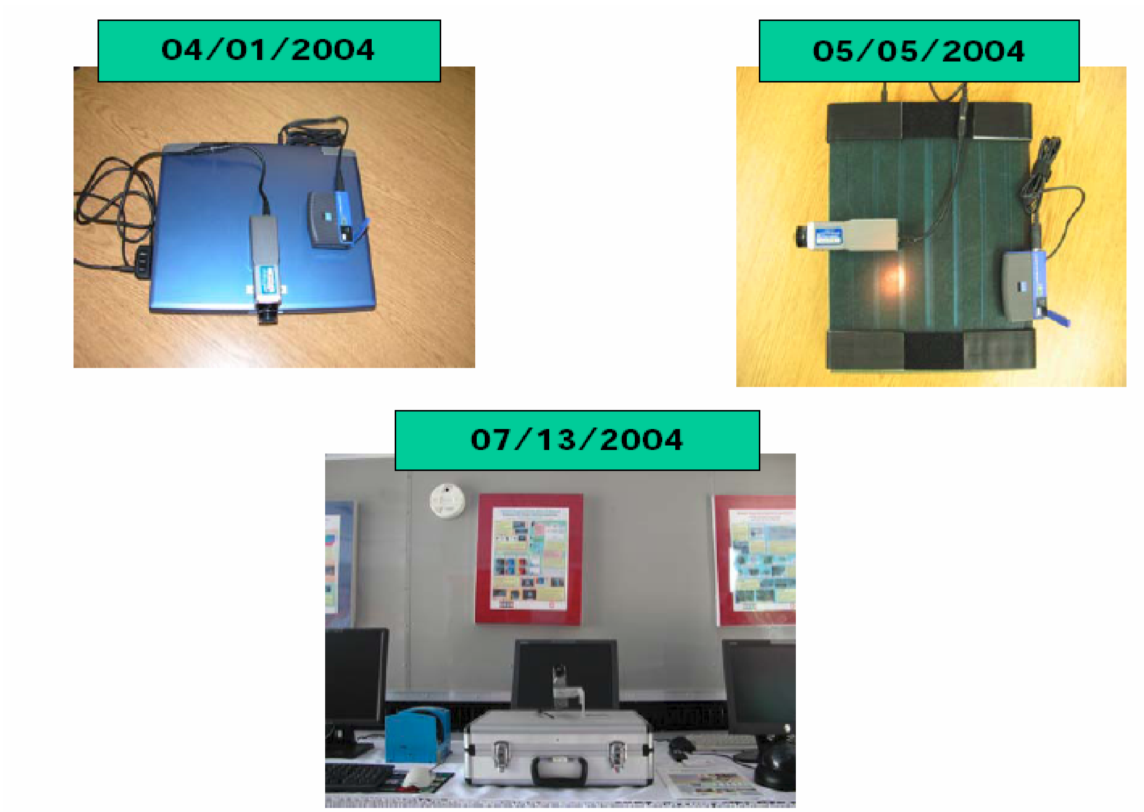


Figure 3.4 Evolution of the infrared imaging sensor brick packaging.

The process of developing a packaged infrared imaging sensor brick system was an evolving one and the packaging went through changes over times. Figure 3.4 above shows the evolution of the thermal sensor brick packaging. Seen in Figure 3.5 and Figure 3.6 below are different views of the finally packaged infrared imaging sensor brick system. A point that needs to be noted here is that the camera can be pulled out from the box and laid horizontally. This is what was done to use the thermal sensor brick as a set up for human detection and intrusion detection.

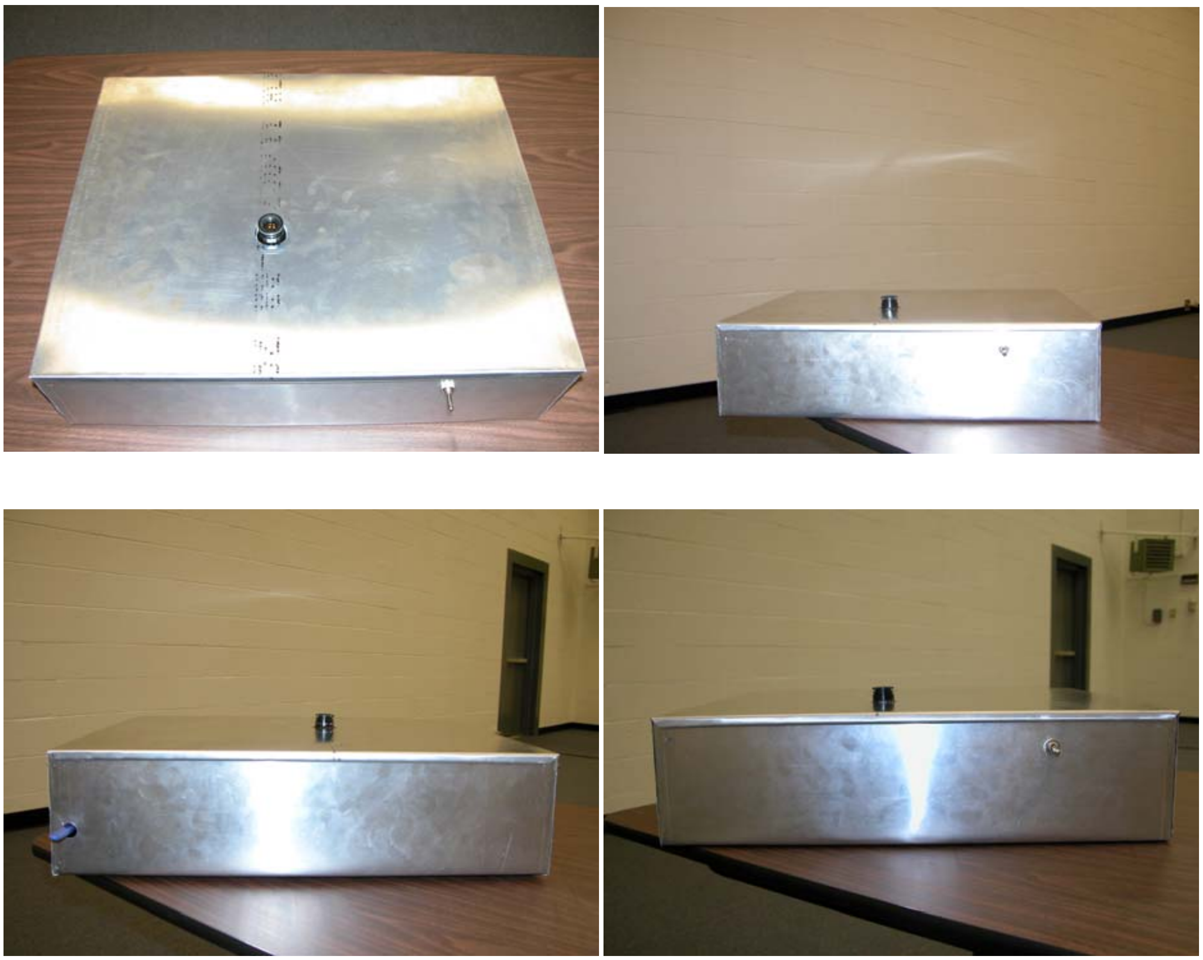


Figure 3.5 Different views of the packaged infrared imaging sensor brick.

Figure 3.6 Different views of the packaged infrared imaging sensor brick mounted on the tracked under vehicle robot.

The infrared imaging sensor brick that has been designed and built by us as described above now has a CAD drawing showing the layout of the components inside the sensor brick as shown in Figure 3.7, it has an electrical drawing showing the wiring connections that are in place inside the box on the sensor brick as shown in Figure 3.8 and a bill of materials giving us the exact description of the components that have gone into the sensor brick is given in Table 2.8.

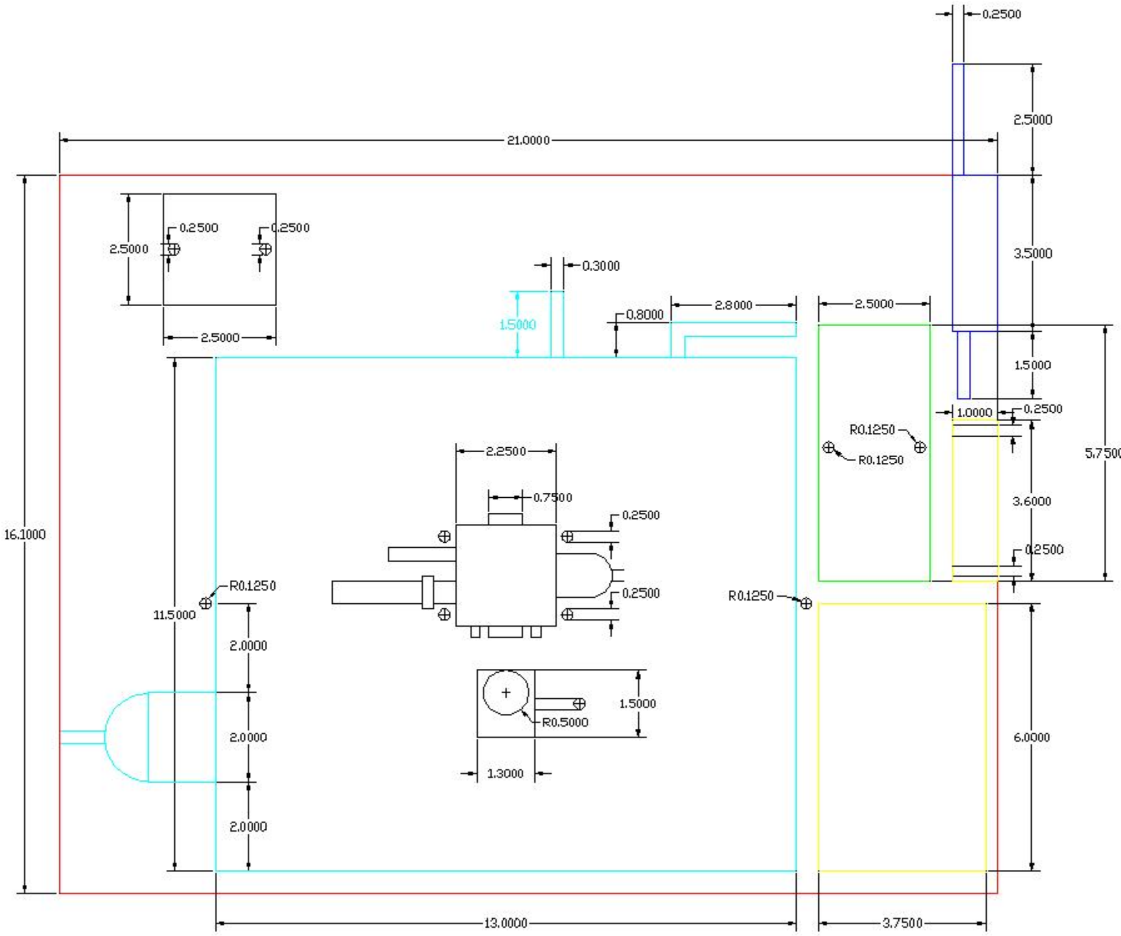


Figure 3.7 CAD drawing of the internal layout of the infrared imaging sensor brick components.

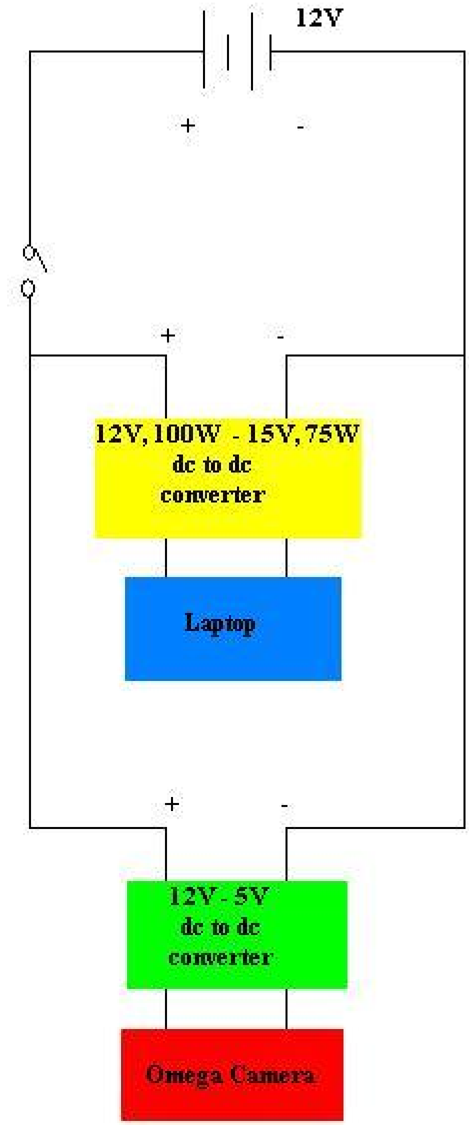


Figure 3.8 Electrical drawing showing the internal connections for the infrared imaging sensor brick.

We selected a 12V battery and then used two dc to dc converters to obtain the desired voltages so as to make all the bricks (Vision, Laser and Thermal bricks) similar to each other and also to maintain the modular nature of the thermal sensor brick. This was felt necessary since on a broader perspective all these bricks are part of the same robot.

Name of the component	Units	Power	Cost
Omega infrared camera (now known as ThermoVision Micron). A thermal camera manufactured by Indigo systems.	1	1.5 W (input)	$16,000
Toshiba Satellite Notebook A-10S129 a 2.4 GHz Celeron notebook computer manufactured by Toshiba Inc.	1	60 W (input)	$1,000
Panasonic LC-RA1212P 12V, 20Ah lead acid battery.	1	240 W (output)	?
VI – 200 (full size) 12V, 100W – 15V, 75W dc-to-dc converter from Vicor.	1	100 W (input) 75 W (output)	$125
VAS1R5 S12 – S5 12V –5V dc-to-dc converter from V-infinity LLC.	1	12 W (input) 1.5 W (output)	$25
IMPERX VCE Pro Fast Analog CardBus video capture card for laptops, from IMPERX.	1	?	$645 + $345(SDK) = $990
WUSB54G 802.11g standard based W-LAN network adapter card from Linksys.	1	?	$25
Printed circuit board	1	-	$5
12V, 0.29 A Brushless CPU fan	1	3.5 W	$15
Input/Output module (power, video, RS 232 and serial digital interface)	1	?	-
12V, 5A ON/ OFF Switch	1	-	$10
Connection splitters	4	-	-
Q – power connector	1	-	$10
Locking DC plug	1	-	$5
Velcro strips	-	-	-
6 – 32 ¼ inch screws, washers and nuts	2	-	-
6 – 32 ½ inch screws, washers and nuts	2	-	-
6 – 32 1½ inch screws, washers and nuts	4	-	-
6 – 32 1 inch spacers	2	-	-
6 – 32 ½ inch spacers	2	-	-
8 – 32 ½ inch screws, washers and nuts	10	-	-
14 gauge red wire	5ft	-	-
14 gauge black wire	5ft	-	-
6 – 32 ½ inch spacers	2	-	-
No: 10 ½ inch spacers	4	-	-
No: 10 ½ inch screws, washers and nuts	4	-	-
No: 8 1 inch screws	2	-	-
Aluminum sheets	2	-	-

Table 3.1 Bill of materials for the infrared imaging sensor brick.

3.2. Software Architecture

After having dealt with the hardware architecture of the infrared imaging sensor brick we now need to take a look at the software architecture. Here we shall deal with the low-level image processing operations that are done at the sensor brick level. These operations are done at the level of the sensor brick and then the processed images along with the raw data are available to the remotely located host computer for further use. These preprocessing operations are of use from a statistical point of view to get some information regarding the image and they also assist in improving the appearance of an image thereby aiding in threat detection.

The processing operations that have been done at the brick level are some basic image processing operations on the acquired infrared images like analyzing the obtained images. Since the raw images obtained from the sensor brick are RGB images we need to obtain the intensity image to perform all the preprocessing operations. These operations include obtaining an intensity image from an RGB image and displaying its histogram. We found that the histogram of an image gave us all the valuable information regarding an image like the gray level intensity distribution which could be used effectively in detecting the presence of objects in a particular region (intrusion detection and human detection). The other operation that has been done on the input image is to pseudo color the intensity image using different color bars. Since both the original RGB image and the intensity image are gray scale images a colored image helps us in getting a better understanding of the image details. A color image gives us some more detailed information like difference in heat patterns in the image and thereby helps us in detecting glaring irregularities (presence of humans and other objects).

In this section below we shall show all the low-level image-processing operations that have been performed on the sample thermal images. This image was captured using our own infrared imaging sensor brick setup with an Imperx frame grabber card and Omega infrared camera. It is an RGB image and is similar to the kind of images that are given out as raw output data from our sensor brick.

3.2.1. Analyzing images

The first thing that was done before the procured images were used for further applications both by the processing block on the brick or by the remotely located host computer was to analyze the images and obtain some valuable information from them. The images obtained from the infrared camera are RGB images that consist of three-color channels and so you need to obtain the intensity image from this that gives us the image representative of the intensity variations in the original input image. The first operation that was done on the image was to obtain the intensity image from the RGB image. This was done for both the background image and the current image and we obtained the difference image from them. Then we obtained the histogram for all these intensity images. The output from this operation on the sample images looked like the one shown in Figure 3.9 below.

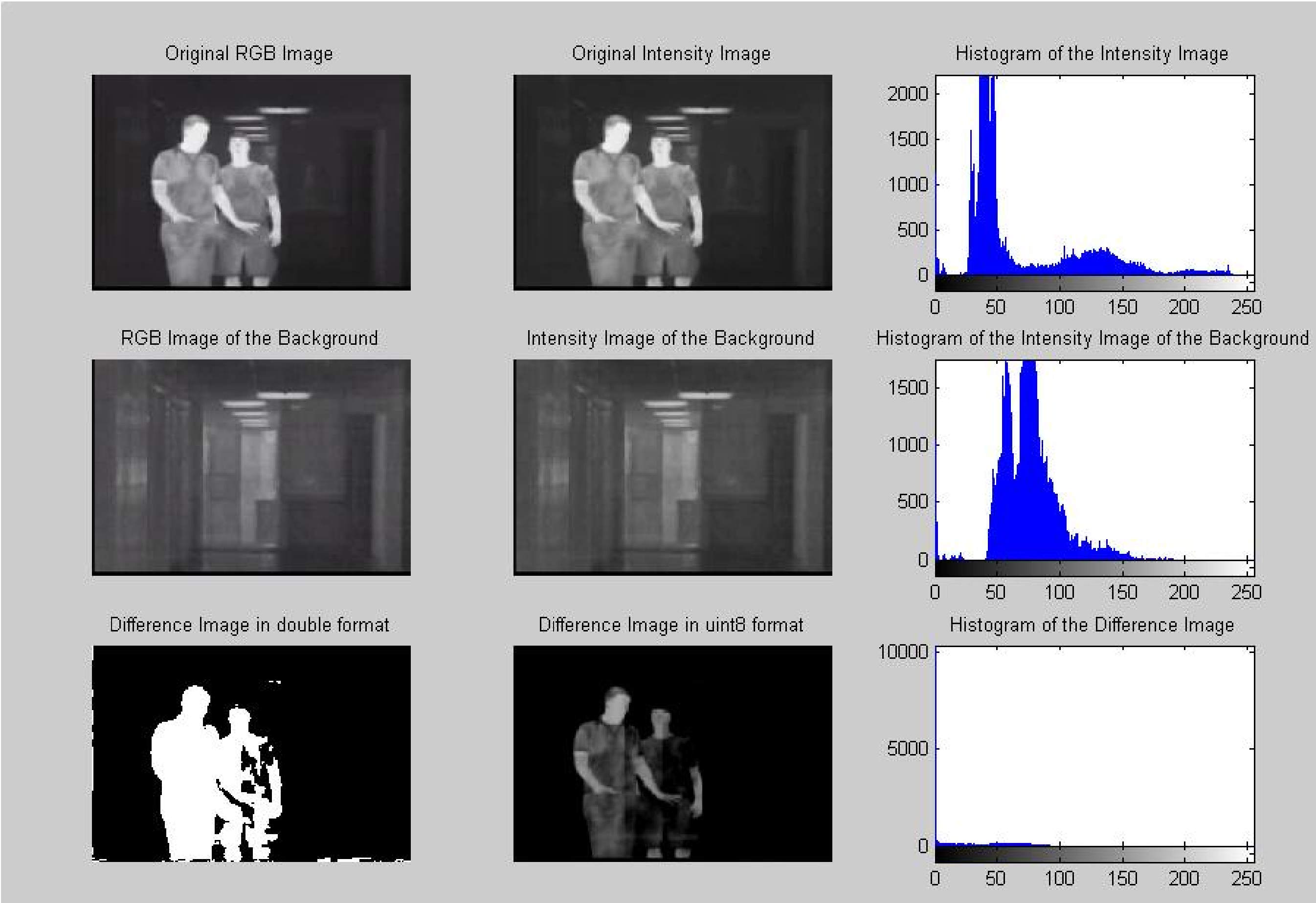


Figure 3.9 The current and the background RGB images, their obtained intensity images and their respective histogram plots.

3.2.2. Pseudo coloring the input images

The other operation that was felt necessary was to pseudo color the intensity image using different color bars. Since both the original RGB image and the intensity image were gray scale images we felt that a colored image would help us in getting a better understanding of the image details. A color image would give us some more detailed information like difference in heat patterns in the image and thereby help us in detecting glaring irregularities (presence of humans and other objects). The output from this operation on the sample image looked like the one shown in Figures 3.10 and 3.11 below.

3.2.3. Intrusion detection using pseudo colored images

We performed the task of intrusion detection on the sensor brick. For this we firstly fixed a background image which is the image of the area that is meant to be guarded against intrusion and then subtracted the background image from the current image which gave us the difference image which helped us in detecting humans and other objects entering that secure location. Some of the possible options tried on the sample image for different color bars are shown in the Figures 3.10 and 3.11 below.

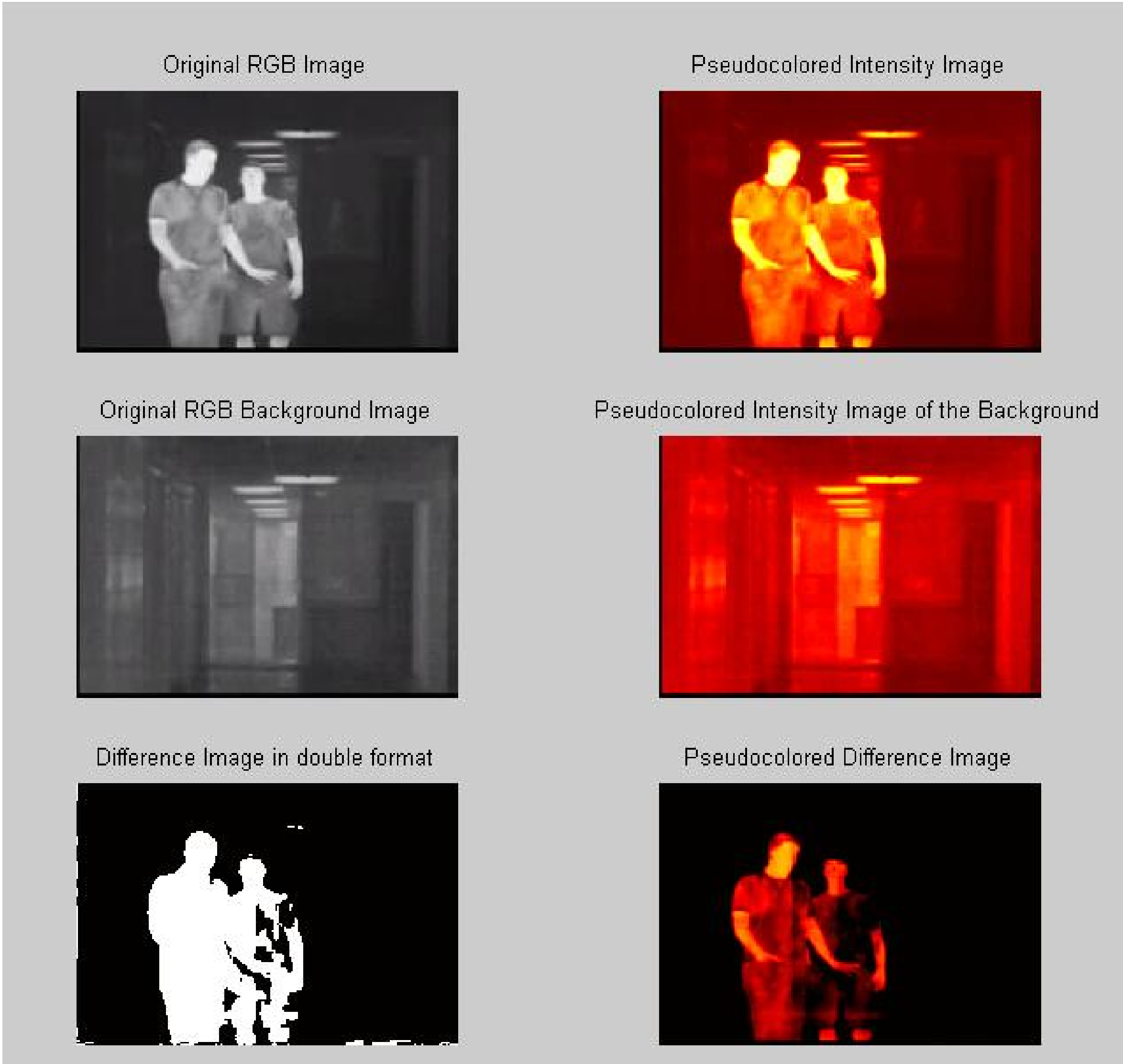


Figure 3.10 The current, the background, and the difference intensity images and their pseudo colored images using color bar HOT.

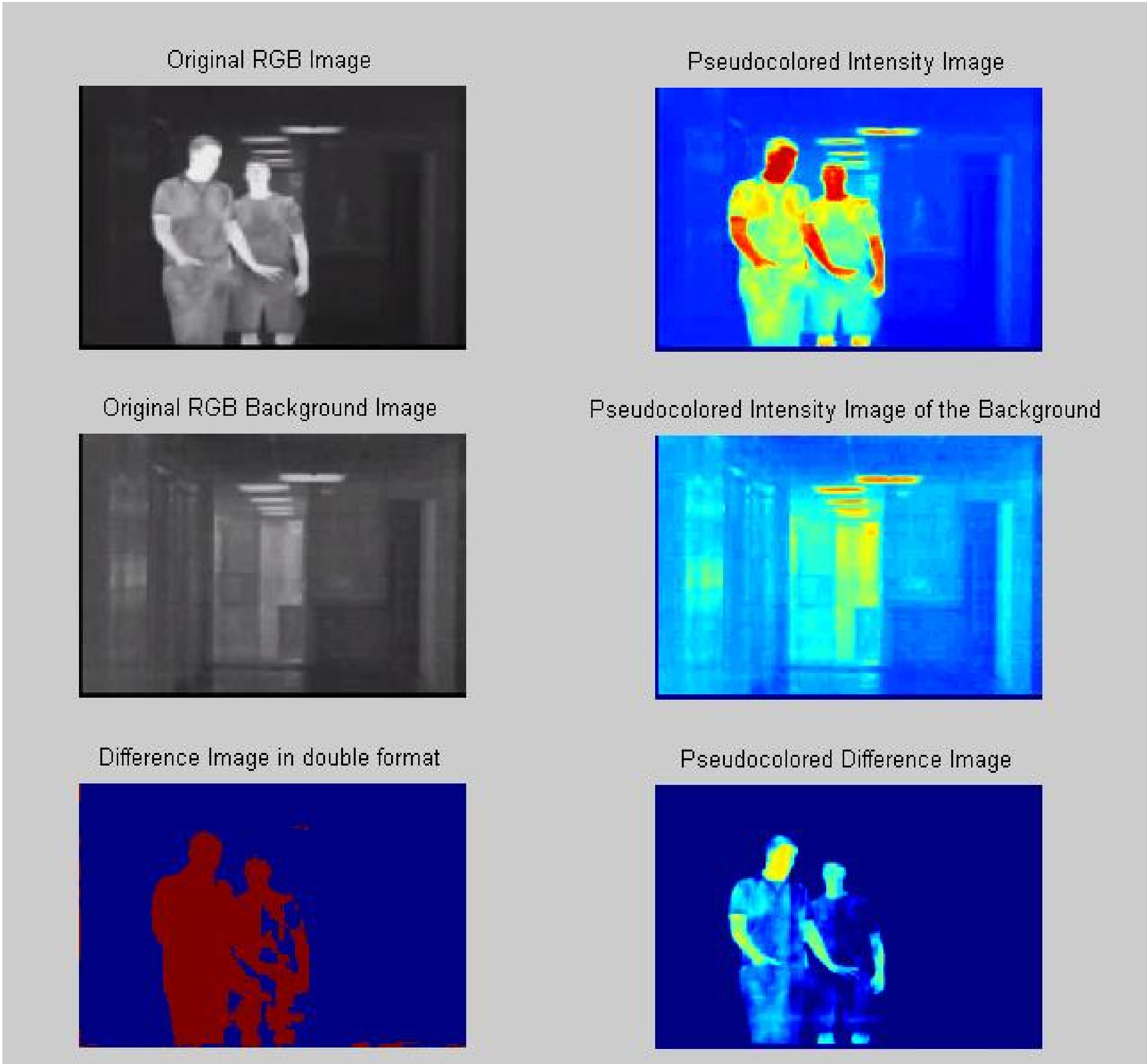


Figure 3.11 The current, the background, and the difference intensity images and their pseudo colored images using color bar JET.

3.2.4. Intrusion detection using edge detected images

Next we performed edge operations on the image for the purpose of edge detection using Sobel, Prewitt, Roberts and Log operators on the intensity image. These operations helped us in detecting humans and other objects in that particular region like in the previous case where we used pseudo colored images. Here also we first fixed a background image and then subtracted this image from the current image. This gave us the difference image on which we performed edge detection operations. Then we converted this difference (intensity) image into a binary image by setting a threshold level. This was done since it is believed that edges are more clearly detected in binary images than on intensity images. The threshold was set manually by looking at the image intensity values in the histogram but we can device a method to do this automatically based on some image parameters. We performed the process of edge detection since this would give us all the edges encountered in the image. Thus this process of edge detection helped us in detecting any humans or objects that may present in the given image. Some of the possible options tried on the sample images with different edge detection operators like Sobel, Prewitt, Roberts and Log are as shown in the Figure 3.13 below. Figure 3.12 shows the process of fixing the background and then subtracting the background for every current image to look for intrusion.

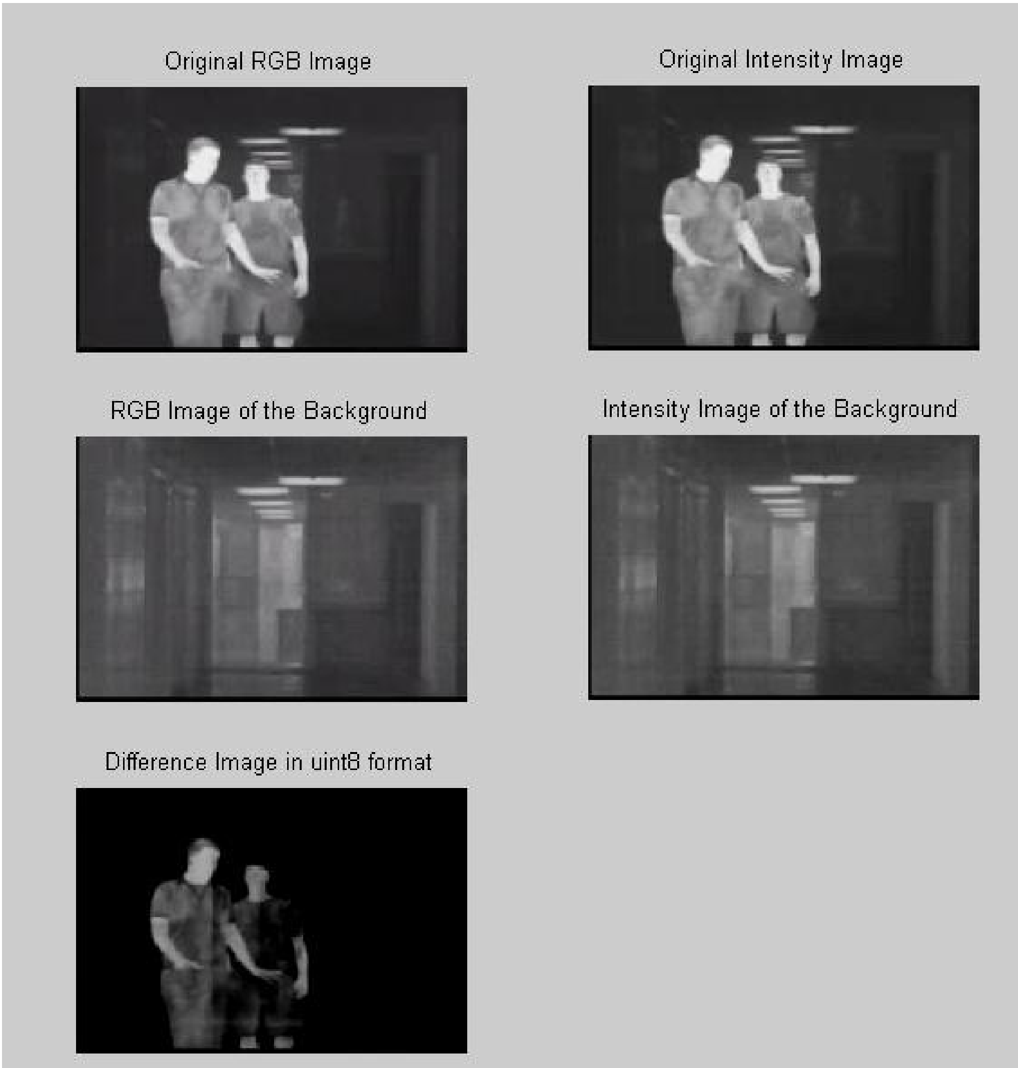


Figure 3.12 The current and the background RGB images, their obtained intensity images, the difference image and the binary difference image obtained after applying a threshold value.

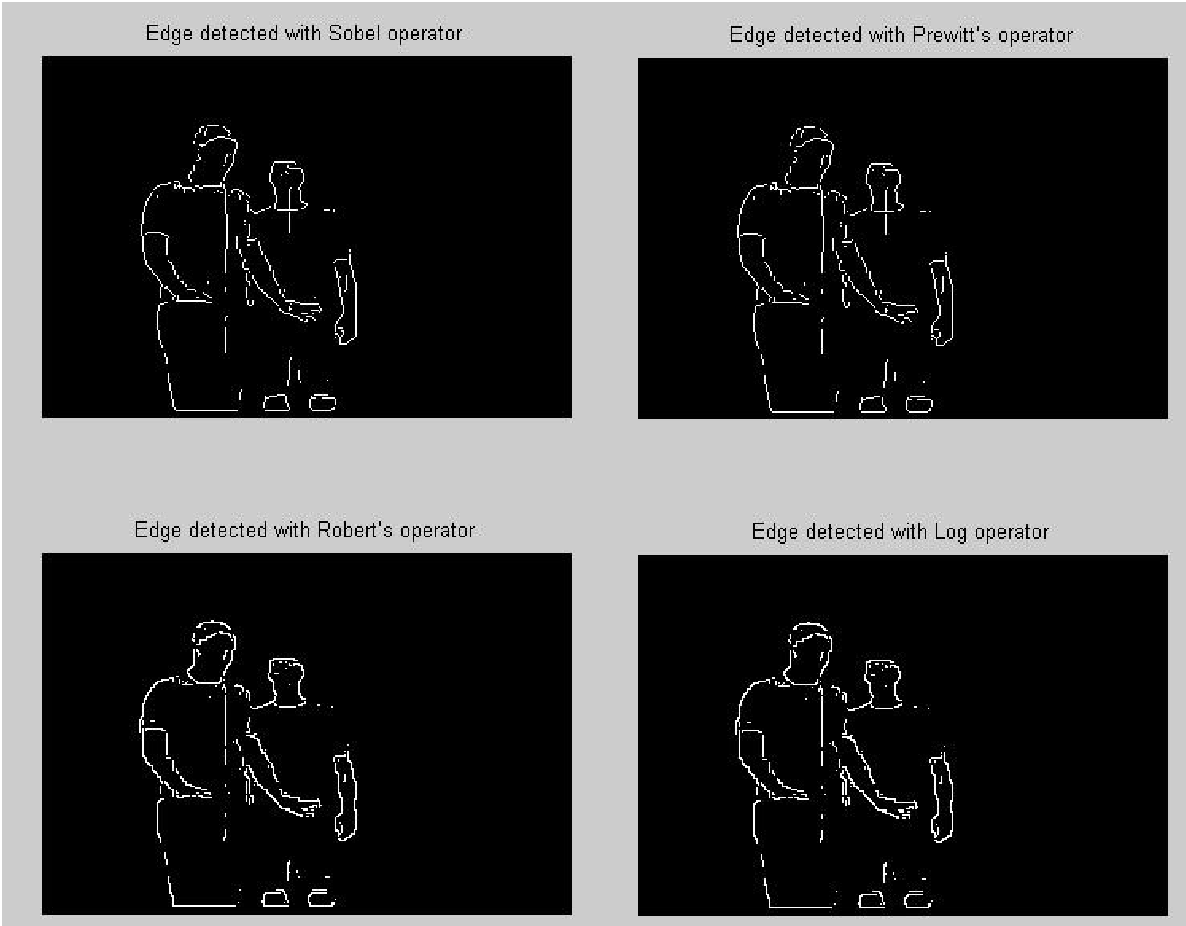


Figure 3.13 The edge detected difference images obtained using Sobel, Prewitt, Roberts and Log operator.

3.2.5. Current version of the thermal sensor brick GUI

In this section we shall discuss the GUI that came along with the Imperx VCE Pro frame grabber card and the GUI that was developed by us for the infrared imaging sensor brick system. The CPU runs on Windows XP as the operating system. The Imperx VCE Pro frame grabber card comes in with a default GUI that helps us in controlling certain features during image capture. We can start and stop the process of both image grab and image capture using this. We can either capture one frame at a time or a sequence of frames or an *.avi file. We can also determine the size of the frame that we want to capture (i.e.) either a full frame or a half frame or a quarter frame. Besides these the other features that we can control are the frame rate, the image brightness, image contrast, image hue and saturation. We can also select the image format in which we want to save the captured file.

The current version of the GUI for the thermal sensor brick that has been developed by us is menu based and it consists of three subsections. First sub section is input which allows us to control the input to the capture card from the camera. This can either be composite 1 or composite 2. The other options are either S Video 1 or S Video 2. The second sub section is called mode which tells whether we are in snap mode or grab mode.

Also this section has status bar option which shows the current values of the image details like brightness, contrast, hue and saturation. The third and the last sub section is called image control, this allows us to vary the image brightness, image contrast, image hue and image saturation within a pre-defined range of values from low to high. All the preprocessing operations that are being performed on the captured data are being performed on a single frame basis. So the processed output data is not a streaming video but is a set of continuously refreshing frames. In Figure 3.14 below we can see a screen shot of the current version of the GUI developed by us in Visual C++. Net.

Figure 3.14 Screen shot of the current version of the GUI for the infrared imaging sensor brick that has been developed by us in Visual C++. Net.

3.2.6. Design of the future version of the GUI

The final version of the GUI for the infrared imaging sensor brick that has been designed is one which is dialog based and it consists of three major sections. They are image capture controls, picture controls and image formats. There are three primary buttons with predefined functions. The first allows us to start grabbing frames, the second allows us to start capturing frames and the last one is to exit the GUI directly. The image capture control section has 11 predefined functions. Three of these functions are to control the frame size (i.e.) either capture full frame size or half frame size or quarter frame size. The next three functions are to control the sequence of data capture (i.e.) either to capture single frame or a series of frames or *.avi video sequence.

There are two features which allow the user to choose between the monochrome gray level intensity image and the pseudo colored image. The feature labeled “Histogram” allows us to obtain the histogram of the intensity image of the current view. The features labeled “Intrusion 1” and “Intrusion 2” allow us to perform the task of intrusion detection. As mentioned in the section on processing and fusion, Intrusion 1 allows us to perform intrusion detection using pseudo colored images and Intrusion 2 allows us to perform intrusion detection using edge detected images.

The picture control section allows us to vary the image brightness, image contrast and image color within a pre-defined range of values from low to high. The controls for these features are available on scroll bar buttons and so these features can be adjusted over a wide range of values. Finally the image control section allows us to select the image format in which to save the single frame or a series of frames that are captured. We have a choice between bmp and jpeg image formats. Seen in Figures 3.15 and 3.16 below are screen shots of the future current version of the GUI designed us in Visual C++. Net.

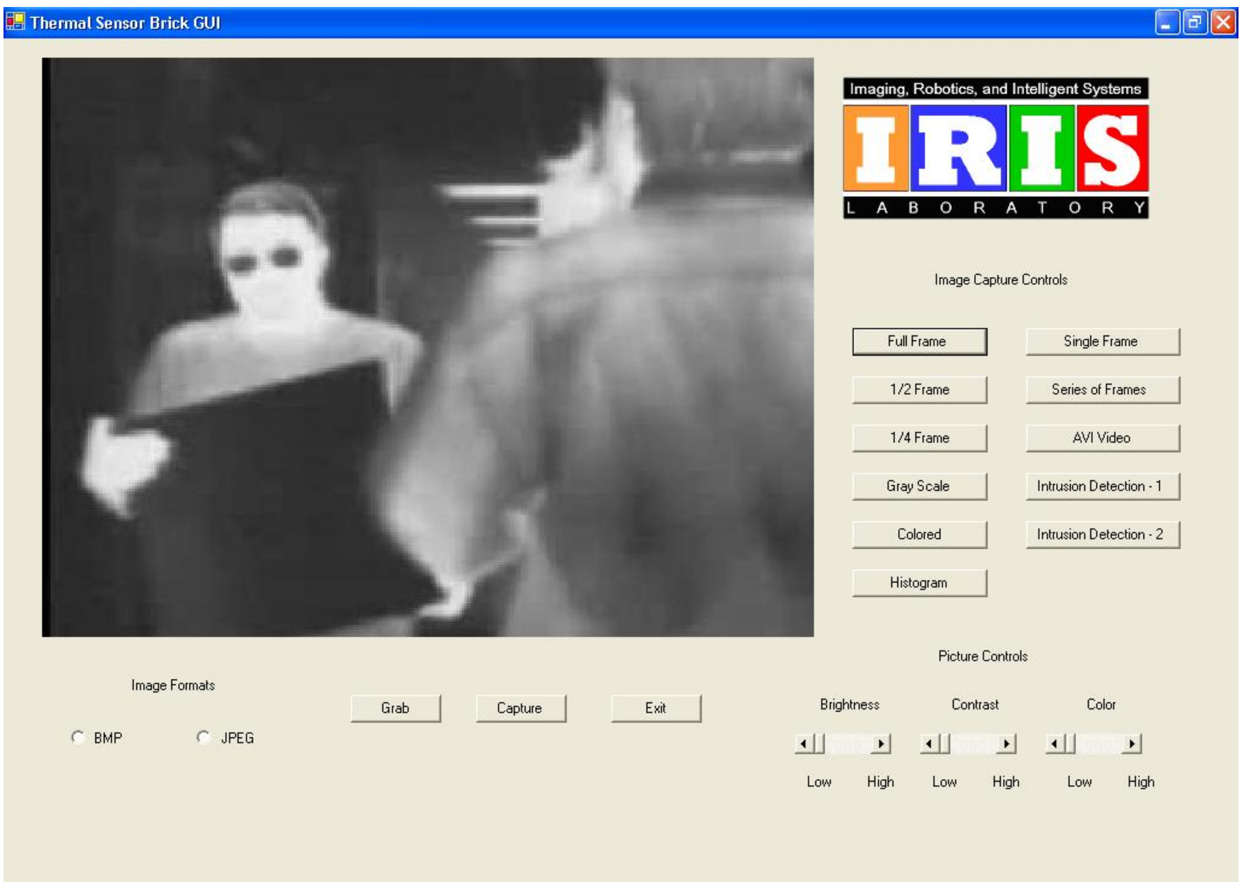


Figure 3.15 Screen shot of the future version of the GUI that was being developed for the infrared imaging sensor brick system. This is a dialog based GUI to be used for human and intrusion detection.

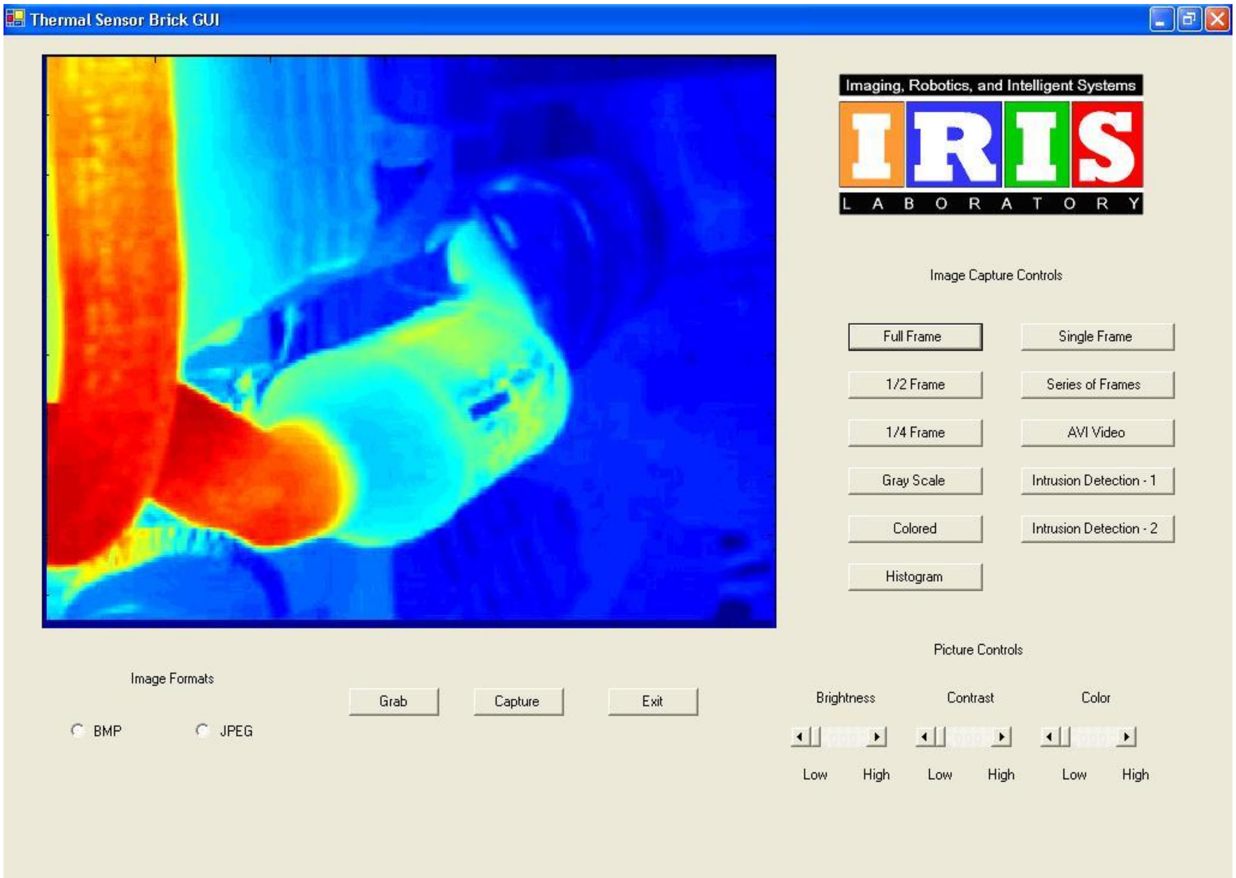


Figure 3.16 Screen shot of the future version of the GUI that was being developed for the infrared imaging sensor brick system. This is a dialog based GUI to be used for under vehicle inspection for threat detection.

4. Experimental Results and Evaluation

As is clear by now from the above sections we successfully designed and built a sensor brick with an infrared sensor on it. This brick turned out to be exactly like how we wanted it to be, a plug and play device. It is a completely self-sufficient system. Since the infrared imaging sensor brick was successfully implemented by us we now needed to perform some experiments using this brick. The infrared imaging sensor brick operated on a single power supply had a complete package and a single ON/OFF switch. The battery power lasted for about 3 - 4 hours of continuous operation of the sensor brick. The tests conducted showed that the infrared imaging sensor brick system could last on its own power setup for up to 3 hours of continuous and guaranteed operation. We were also able to perform some proposed on brick processing operations. We were also successful in designing an indigenous GUI for the thermal sensor brick but it did not work completely in real time.

4.1. Data collection with thermal sensor brick

We used the thermal sensor brick to capture data to test its setup for human detection and intrusion detection. We also captured two (2) different sets of under vehicle thermal video sequences. They were as follows: -

- Thermal video sequence of the entire under vehicle. (Under all possible normal conditions looking out for variations over a period of time)
- Thermal video sequence of the entire under vehicle with a threat object. (With a bomb/ other unwanted hidden / threat object).

4.1.1. Under vehicle thermal video sequences (variations with time)

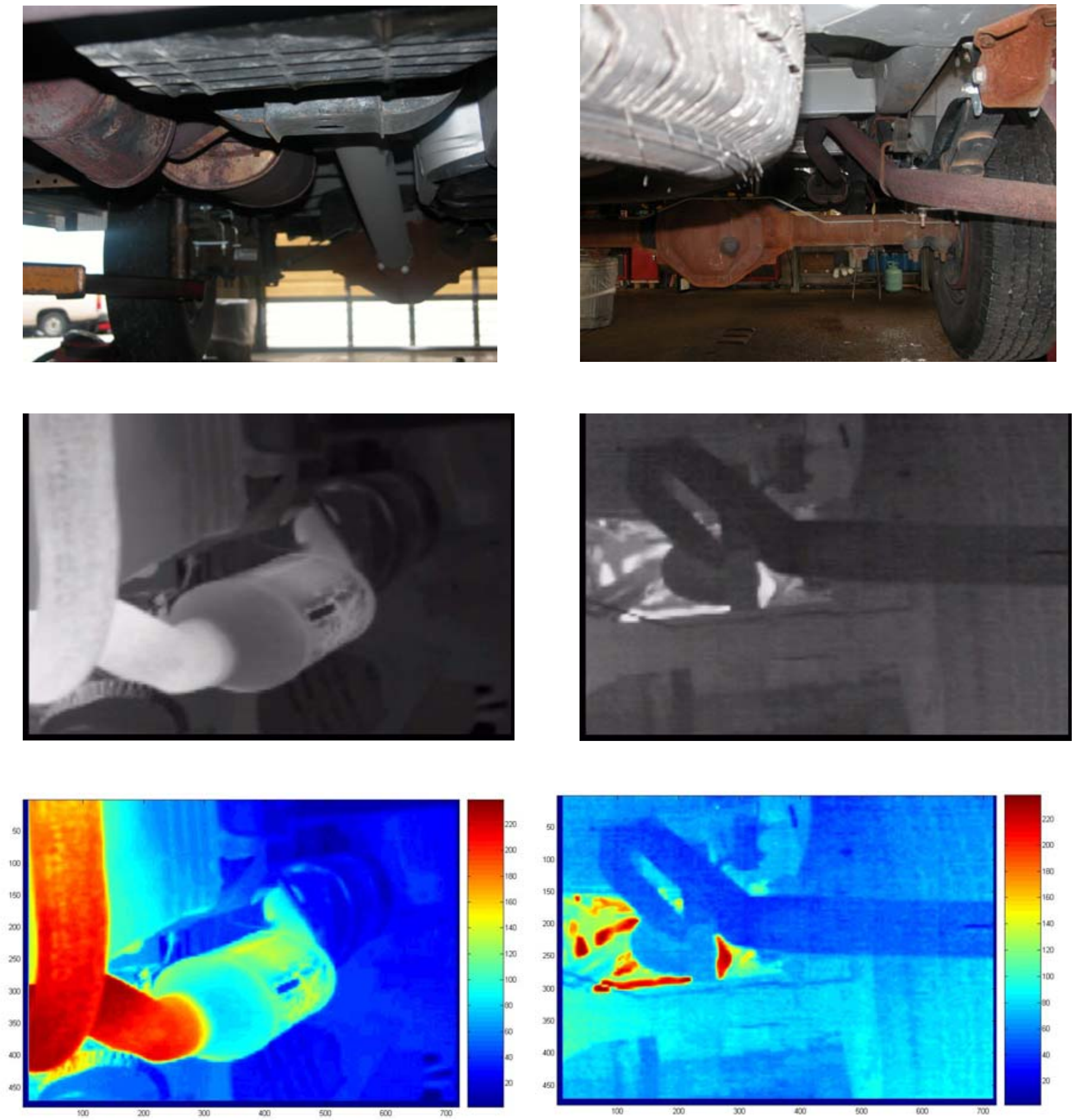
In this section we captured three different thermal video sequences to look for variations in under vehicle conditions over a period of time. The 3 different fields of view were: -

The catalytic converter and the muffler.

The muffler and the exhaust pipe.

The fuel tank and the axle.

All the data was acquired using the infrared imaging sensor brick system designed and built by us and the process was carried out at the UT motor pool using a Dodge RAM 3500 IRIS Van. Also the camera was setup in the smart scene mode. In Figure 4.1 below we can see a single frame of the under vehicle thermal video sequence taken to observe variations with time, for each field of view we can see the visual image, the acquired thermal image (gray scale) and the pseudo colored thermal image.



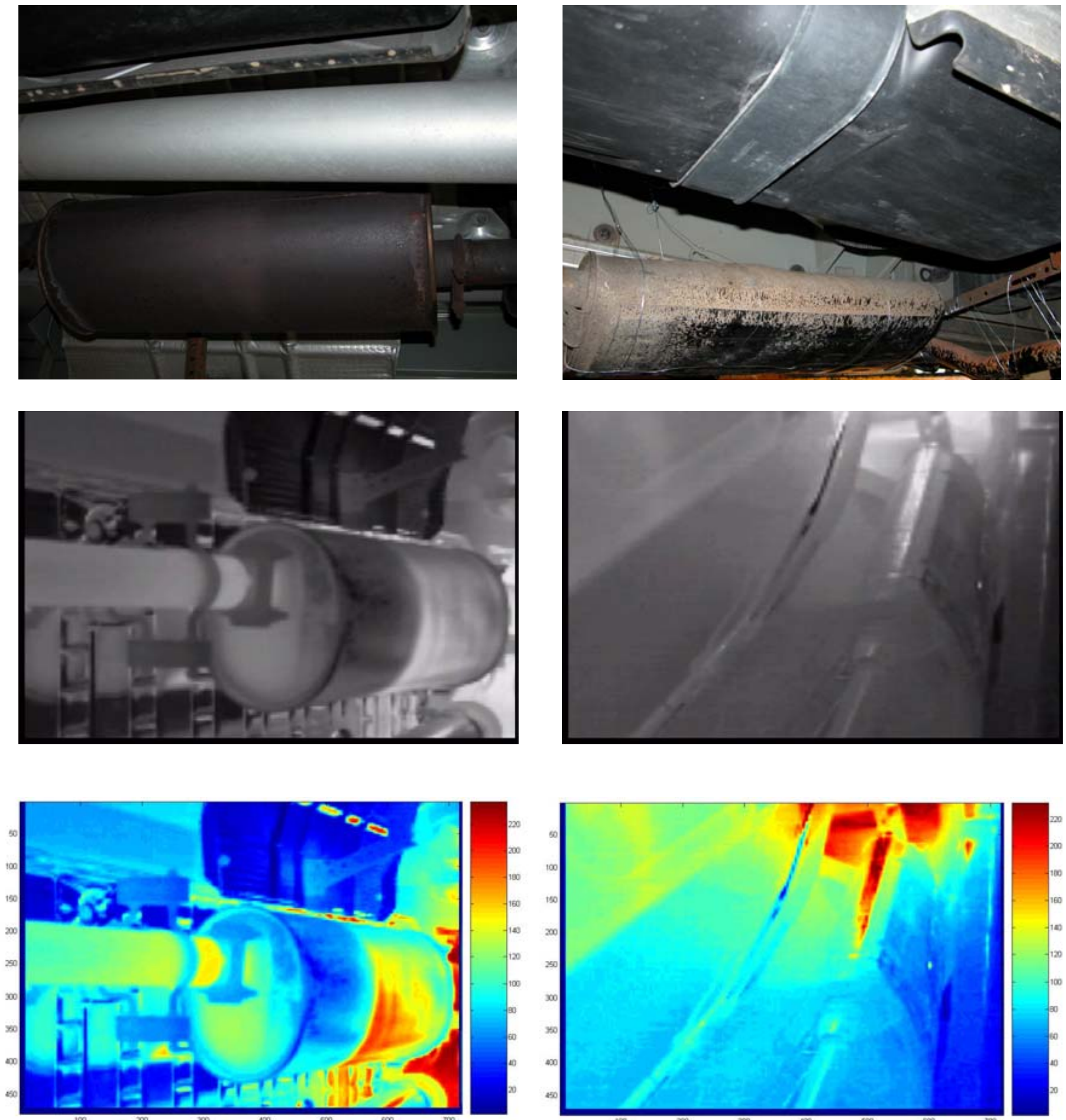
Section showing the catalytic converter and the muffler.

Section showing the muffler and the exhaust pipe.

Figure 4.1 Under vehicle thermal video sequence (for variations with time).

4.1.2. Under vehicle thermal video sequences (for normal expected results and for hidden/threat object)

In this section we captured different thermal video sequences to look for expectations and for hidden/possible threat objects, which may not be visible under normal visibility conditions but the difference in temperature from the surroundings may highlight their presence. Under expectations we looked for sections that we knew would both be hot or cold and check if they were really so. If not then we could safely assume that something was wrong in that section of the vehicle. These data sets went a long way in highlighting the advantages of the thermal camera in detecting threats that may remain invisible through a normal vision camera. We also imaged certain sections of the under vehicle to look for expected results (i.e.) to check if the catalytic converter and the muffler were hot as expected and whether, the fuel tank and the axle were cold as expected.



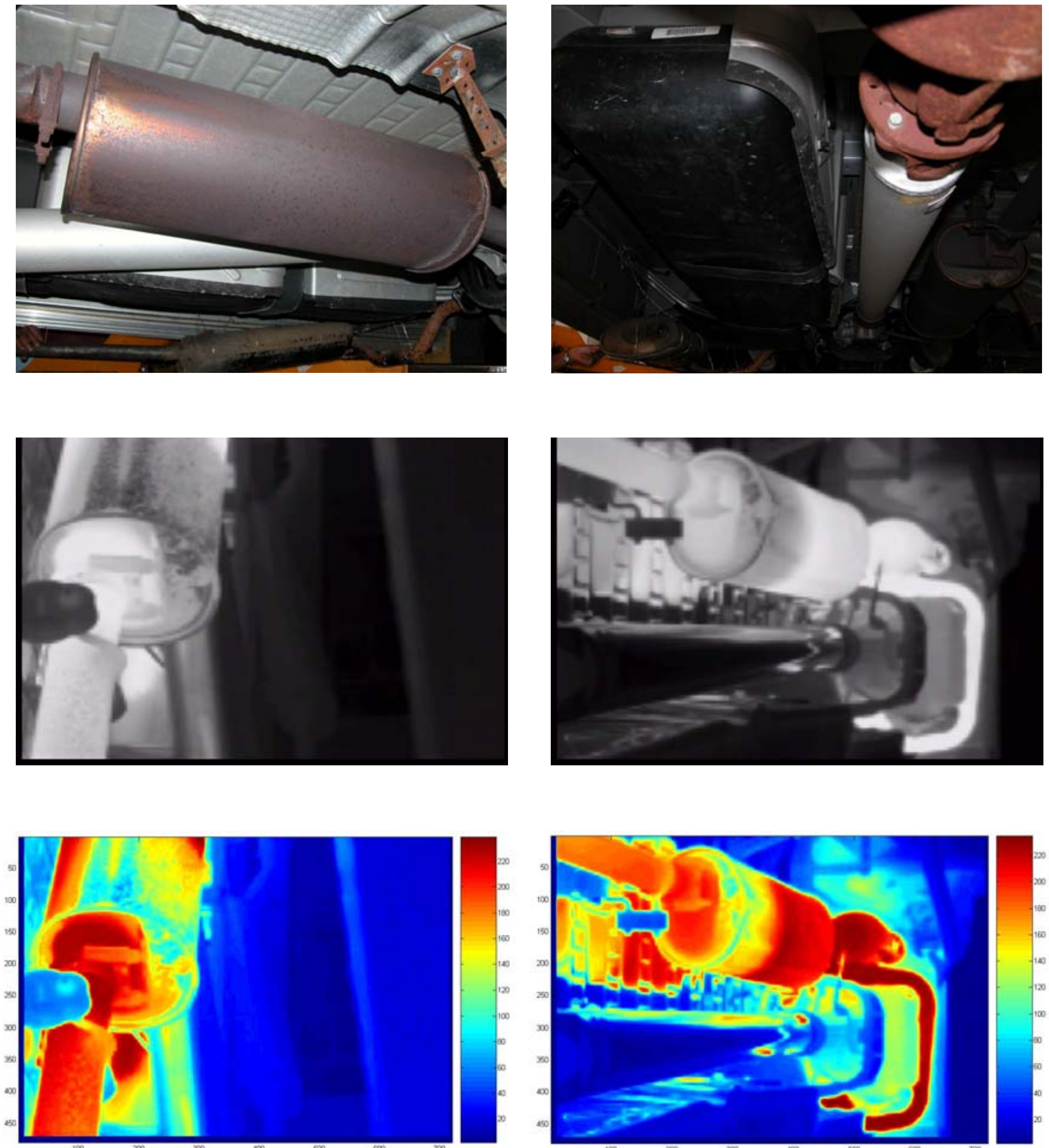
Section showing a true muffler, which is hot as expected.

Section showing a false muffler, which is cold and so, should be suspicious.

Figure 4.2 Under vehicle thermal video sequence (Normal expected results).

In Figure 4.2 above and Figure 4.3 below we can see single frames of the under vehicle thermal video sequence taken to observe normal expected results, in Figure 4.4

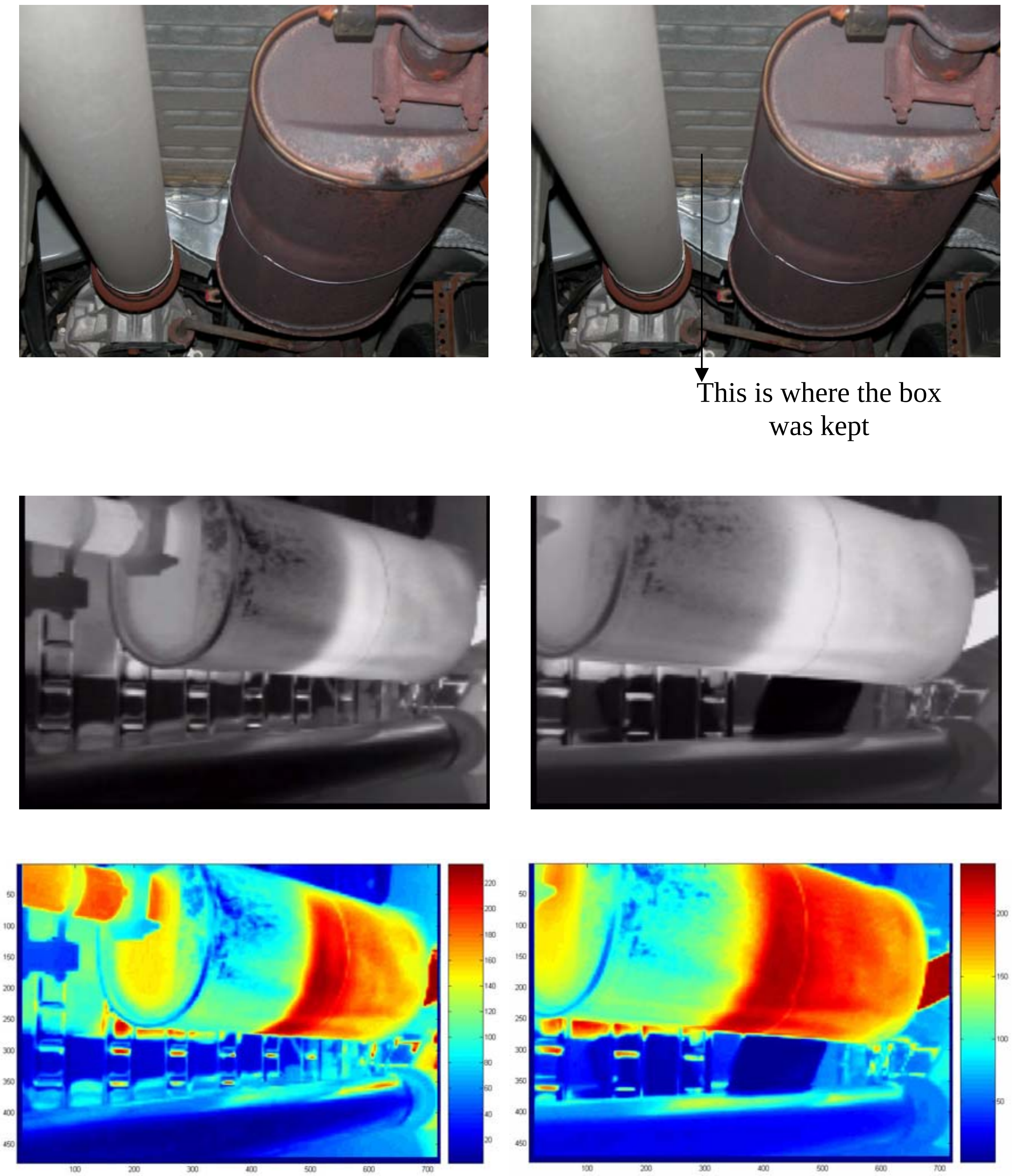
below we can see single frames of the under vehicle thermal video sequence taken to observe hidden object.



Section showing a true muffler, which is hot as expected and a false muffler, which is cold.

Section showing a broad view of the under vehicle of the van.

Figure 4.3 Under vehicle thermal video sequence (Normal expected results).

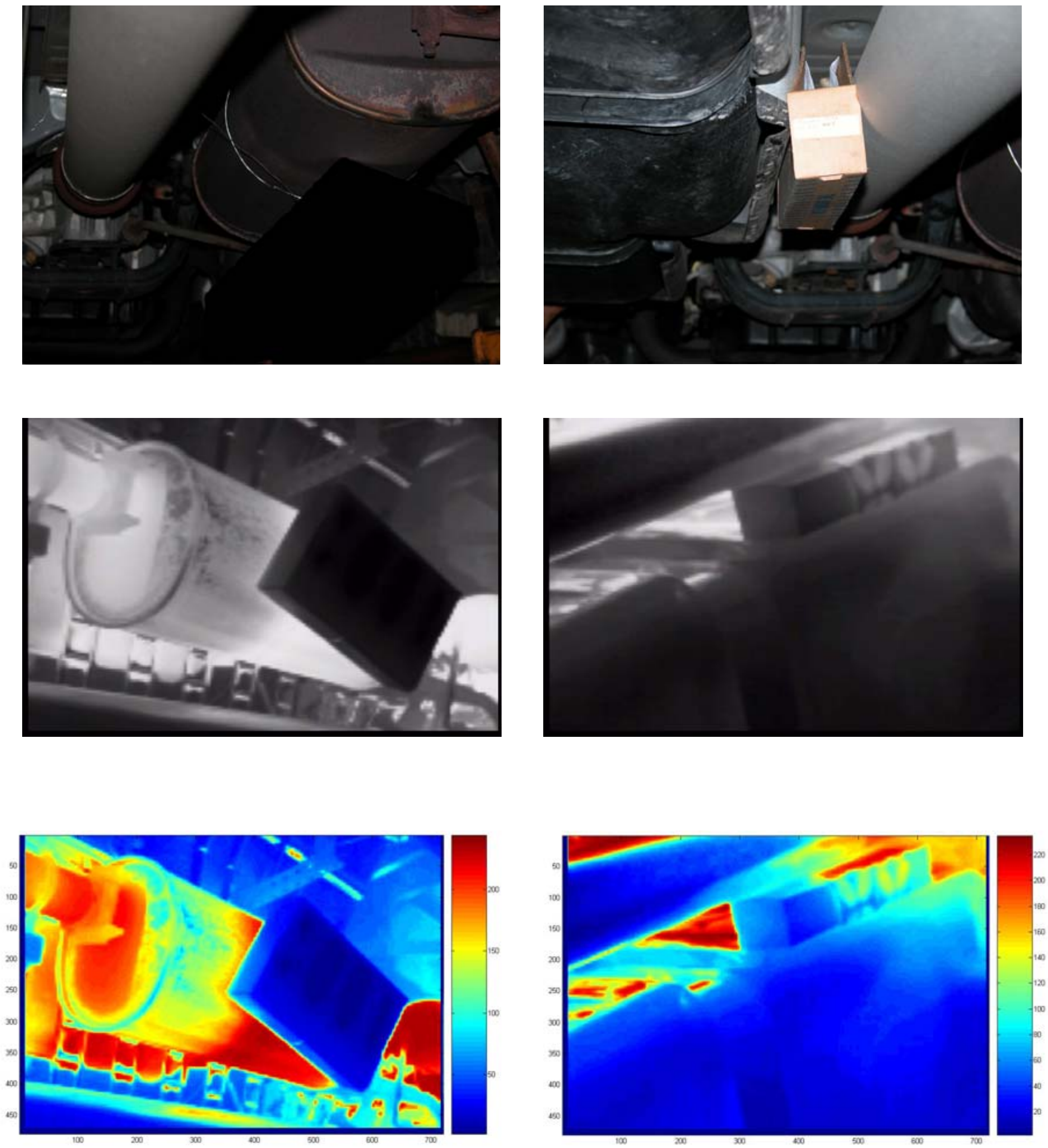


Section showing the area with the muffler and the axle rod.

Section showing the area with the muffler and the axle rod with a hidden box in between the two of them.

Figure 4.4 Under vehicle thermal video sequence (Hidden object).

In Figure 4.5 below we can see single frames of the under vehicle thermal video sequence taken to observe possible threat object. For all the above mentioned figures for each field of view we can see the visual image, the acquired thermal image (gray scale) and the pseudo colored thermal image.



Section showing the area around the muffler (hot) with a suspicious (cold) object tied around this. This cannot be seen in the visual image.

Section showing the area around the gas tank (cold) with a suspicious (hot) object placed near it.

Figure 4.5 Under vehicle thermal video sequence (Threat object).

5. Conclusions

We were successful in designing and implementing the sensor brick with an infrared sensor (Omega infrared camera) on it. This brick turned out to be exactly like how we had conceptually wanted it to be, a plug and play device. It is a completely self-sufficient system. Since our goal for this project was to design and implement the infrared imaging sensor brick system we accomplished our task and so the project was complete. Since our ultimate goal was to develop a sensor brick, which would firstly be completely modular and like a plug and play device; hence we wanted it to be light in weight and completely self-sufficient. We were able to keep the weight, size and power consumption on the lower side by using the Omega infrared camera as our sensor. The brick was able to maintain its flexibility in being capable of communicating with the host computer from any location by employing the 802.11g W LAN network adapter card. The laptop which was used as the CPU on the sensor brick to perform some on brick processing operations on the captured infrared images helped in reducing the size of the whole system. The entire infrared imaging sensor brick setup operated on a single 12V power supply. This battery was able to power the CPU and the camera. The brick housed in a 21” X 17” X 5.25” aluminum box built for it by us.

The sensor brick with (Omega infrared camera) as the infrared sensor on it was successfully tested. We were successful in capturing live data and streaming it out in real time over the W LAN to the host computer using remote desktop connection. The thermal data was captured using a frame grabber card connected to the CPU. We could capture a full frame size; half frame size and quarter frame size of data. Also the frame capture rate could be adjusted as per our need. The system lasted on its own power set up for about 4 hours. We were also able to capture some under vehicle data using the infrared imaging sensor brick system by setting it on the tracked under vehicle robot. These data sets captured helped in highlighting the advantages of the thermal camera over a normal vision camera. We also showed the advantages of the proposed processing operations on the infrared imaging sensor brick. We were also successful in designing an indigenous GUI for the thermal sensor brick and building its first version. The thermal brick now has its own GUI that can be used for data capture but as yet it does not process data in real time.

6. Future Work

We developed an indigenous GUI for the infrared imaging sensor brick system but it was menu based. The dialog based version of the GUI which was designed by us does not run in real time and so this can be an immediate future work. Also we could explore all the possible options for setting up live streaming video over the internet. As far as the hardware aspect of the design is concerned the brick could still reduce in size. This could be achieved by using a smaller laptop as a CPU on the brick and also maybe design a more sleeker and compact package using all other components which are smaller in size. We could also consider an alternate battery which is smaller in size.

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Appendix I

The below specified design of the thermal sensor brick was done during fall 2003 as part of my ECE 573 course. This design was taken as reference and modifications done to it, so as to develop the final design of the thermal sensor brick that has been implemented. It has been mentioned here as a reference for future designers who might review this work to get an understanding of the evolution process [8].

DESIGN: 1

Central Processing Unit of the Brick (motherboard, processor, RAM, frame grabber card, hard disk, floppy drive, CD – ROM drive and power supply)	***Sensor*** (Omega infrared camera and its power setup)	***802.11g W-LAN for Communication*** (The power for the W-LAN would be drawn from the CPU power system because the two would never work in isolation)

Figure A.1 Hardware architecture of the original design for the thermal sensor brick. This design was done as part of my fall 2003 ECE 573 course.

Sensor: the infrared sensor on our sensor brick was the Omega infrared camera manufactured by Indigo systems. The camera came equipped with its own power setup. It had a battery pack that consisted of rechargeable lithium batteries and could provide up to 2 hours of uninterrupted camera power. The video output could be obtained via an RCA connector. The battery pack and the charger could together provide up to 4 hours of camera operation in suitable environments [5].

The Central Processing Unit: here was where the thermal images captured by the Omega infrared camera were supposed to have been procured, stored, processed and transmitted. The components that would have gone in to make the CPU were: -

- Motherboard – the motherboard that was originally selected for our sensor brick was the P4GE – VM manufactured by ASUSTeK computer Inc [10], [11]. The specifications are as given below (they have been reproduced from the manufacturer's website)

Processor type and Cache	Socket 478 for Pentium 4/Celeron up to 3.06GHz+. On-die 512KB/256KB L2 Cache.
Chipset	Intel 82845 GE GMCH, Intel 82801 DB ICH4.
Back Panel I/O Ports	1 x Parallel; 1 x Serial; 1 x PS/2 Keyboard; 1 x PS/2 Mouse; 1 x VGA; 1 x Audio, I/O; 4 x USB 2.0; 1 x RJ45 (on LAN model only).

Memory	2 x 184-pin DIMM sockets support max. 2GB PC2700/PC2100 (FSB533) or PC2100/PC1600 (FSB400) non-ECC DDR SDRAM memory.
Front side bus	533/400 MHz.
Expansion slots	1 x AGP, 4 x (1.5V only) (optional) and 3 x PCI.
VGA	Integrated 3D graphics ADD card (DVI-845) support (1.5V AGP cards only) AGP 4 X (optional).

- Processor – a 2.4 GHz, Intel Pentium 4 CPU with a 512 K cache memory and a front side bus of 533 MHz was selected [11].

- RAM - 1GB RAM. Standard 128M X 72 ECC 133MHz 168-pin (SDRAM, 3.3V, CL3, 400mil, TSOP, double-sided, gold) was considered necessary for the CPU.

- Frame grabber card - The frame grabber card that was short-listed for the system was Pixelsmart512-8 from Pixelsmart. It had a 256K-image buffer with a possible up gradation to 2/4/8/16/32/64 images and it could give up to 512 X 512 resolution [13]. It was both NTSC and PAL compatible and had a look up table for color outputs (optional false coloring) [13]. It also came in with 1 composite video input (2/4 input option).

- Hard disk – Barracuda ATA V an 80 GB, 7200-rpm hard disk from Seagate was the one selected for that system. It had an average seek time of 9.4 ms and an Ultra ATA/100 interface [12]. The model product number was (ST380023A). Some of its major advantages were:

1. It had a 7200-rpm desktop performance, which helped to improve the overall PC performance. The 2 MB cache buffer on it also helped to improve its performance significantly.

2. It had a 350 Gs non-operating shock which gave the drive protection from all shocks and vibrations.

3. The Ultra ATA/100 interface on it allowed it to transfer data at the fastest possible transfer rates.

4. The 3D defense system on it provided for a comprehensive drive and data protection system.

- Floppy drive or ZIP drive – we suggested to fit a floppy drive and a ZIP drive and keep the option of choosing any one or both of them as per the need be. The floppy drive would have been a 1.44 MB floppy drive and the ZIP drive would be "Zip" a 750 MB USB 2.0 external drive from iomega [14].

- CD – ROM drive – we also suggested to fit a CD-ROM drive to the computer. It would have been a 48 X Hewlett Packard HP (DC143B) Internal CD-ROM Drive which had a volume of ~ 68 in^3 and a weight of 800 grams [15].

- Power supply – the CPU setup required a regulated power supply. The power supply that was designed to be on the CPU was PW–70–MINI–ITX dc-to-dc converter; it was a 70W dc-to-dc converter, which operated on a dc input voltage of 12V. It had a combined power output of 100W, which in our estimate should have been sufficient to power both the CPU and the wireless card [11], [16].

802.11g for Communication: after a thorough review of all the possible communication systems which included wired communication, TCP/IP, different wireless LAN standards, Cellular technology and Bluetooth technology, we short-listed on W LAN for the purpose of communication on the sensor brick. The W LAN network adapter card that we selected was WMP54G from linksys. It could be fitted to the PCI slot on the CPU. This Wireless G (802.11g) helped in connecting to a wireless network with speeds of up to 54Mbps and was also reverse compatible with 11Mbps 802.11b cards [17]. The Wireless G had an up to 128-bit encryption protection along with the new industrial strength (Wi – Fi protected access) WPA security [17]. The design was such that the wireless network adapter card would operate on power drawn from the CPU.

Appendix II

The below specified design was obtained by modifying the original design mentioned in Appendix I. While designing this system our main consideration was in reducing the size of the CPU so that it would serve the purpose of using a really small camera like Omega on our sensor brick. This was our intermediate design before we reached the final one which has been implemented. It has been mentioned here for reference for future designers who might review this work to get an understanding of the evolution process [8].

DESIGN: 2

Central Processing Unit of the brick	***Sensor***
(Shuttle PC with 802.11g W-LAN for communication connected to it through the USB port on it.)	(Omega infrared camera and its power setup)

Table A.1 Hardware architecture of the thermal sensor brick which was redesigned the first time to make the CPU smaller in size.

Sensor: the infrared sensor on our brick was the Omega infrared camera manufactured by Indigo systems. The camera had its own power setup. It had a battery pack, which consisted of rechargeable lithium batteries that could provide up to 2 hours of camera power. The video output was obtained via an RCA connector. The battery pack and charger could ensure up to 4 hours of camera operation in suitable environments [5].

The Central Processing Unit: this was where the images captured by the Omega infrared camera would be obtained, stored, processed and transmitted. The CPU was a ST62K ATI RS300 based XPC. It was a Shuttle PC [9]. Figure A.2 shows pictures of the front and back panels of the shuttle PC.

All the below mentioned technical specifications of the Shuttle PC have been obtained from the official website of Shuttle Inc. [9].

- Processor: Intel Pentium 4/Celeron in the 478 pin package with 400/533/800MHz FSB.

- Chipsets: ATI RS300 + IXP150. Support dual channel DDR200/266/333/400 DDR SDRAM interface. Built in ATI Radeon 9100 based 2D/3D graphic core.

- Memory: 2 x 184 pin DDR SDRAM DIMM slots.
  Support PC1600/2100/2700/3200 compliant DDR SDRAM up to 2GB capacity.

- VGA: Integrated high performance ATI Radeon 9100 graphic core.

- TV-out: Support NTSC and PAL format in S-video/composite terminal support maximum input active resolution up to 1024 x 768.

- Onboard header:
  1. 2 x UDMA100 IDE ports.
  2. CD_in & Aux CD_in headers.
  3. 4-pin ATX 12V/5V power header, 3 fan connectors.
  4. Parallel port, IrDA header.
  5. Dual USB ports header, SPDIF in header.

- IEEE1394a: VIA VT6307, compliant with 1394 OHCI specification version 1.0, up to 400Mb/s data transfer rate.

- Fast Ethernet: Onboard Realtek 8100C supports 10/100 LAN operation.

- PCI slot: 1x 32bit/33MHz PCI slot.

- Audio: On board Realtek ALC650 six channel audio.

- Front panel:
  1. 2 x USB ports, 1 x Line-in, 1 x Mic-in, 1 x Line-out.
  2. 1 x Power-ON button, 1 x Reset button.

- Back panel:
  1. 2 USB 2.0 ports, 2 IEEE 1394 connectors.
  2. 1 PS/2 keyboard port, 1 PS/2 mouse port.
  3. 1 Rear out, 1 Front out, 1 Center/Bass connectors.
  4. 1 RJ45 LAN port, 1 Serial port, 1 VGA port.
  5. SPDIF out, 1 TV-out port, Clear CMOS button.
  6. 12V power adapter connector.

- Extension bay: 2 x 3.5” bays, 1 x 5.25” bay.

- Dimension: 190(L) x 170(W) x 280(H) mm, 2.1Kg (N.W), 5.2Kg (G.W).

- Material: Aluminum.

- Power adapter:

  1. Dimension: 178 x 120 x 54.5mm.
  2. Input: 90~264V AC,
  3. Output: 12V, 180W.
  4. Power cord: depends on specific region demand.

- Accessories:
  1. 1 x Main board user manual.
  2. 1 x Main board CD-driver.
  3. 1 x XPC installation guide.
  4. 1 x I.C.E. technology CPU heat-pipe.
  5. 2 x HDD cable.
  6. 1 x CD-ROM cable.
  7. Screws, twin adhesive, friendly front feet, IDE power cable.

Figure A.2 The front and back panels of the Shuttle PC respectively. This was the CPU for our revised version of the design.

- RAM: 1 GB RAM, Standard 128M X 72 ECC 133MHz 168-pin.

- Frame grabber card: The frame grabber that we had short-listed for our system was Pixelsmart512-8 from Pixelsmart. It had a 256K-image buffer with a possible up gradation to 2/4/8/16/32/64 images and could give up to 512 X 512 resolution [13]. It was both NTSC and PAL compatible and had a look up table for color outputs (optional false coloring) [13]. It came in with 1 composite video input (2/4 input option).

- Hard Disk: Barracuda ATA V an 80 GB, 7200-rpm hard disk from Seagate. The hard disk had an average seek time of 9.4 ms and an Ultra ATA/100 interface [12]. The model product number was (ST380023A). Some of its major advantages were:
  1. It had a 7200-rpm desktop performance, which improves the overall PC performance. Also it had a 2 MB cache buffer that improved its performance significantly.
  2. It had a 350 Gs non-operating shock which gave protection to the drive from all shocks and vibrations.

3. The Ultra ATA/100 interface on it allowed it to obtain fastest possible data transfer rates.
4. 3D defense system provided a comprehensive drive and data protection system.

- ZIP drive: The ZIP drive would be “Zip” a 750 MB USB 2.0 external drive from iomega [14].

- CD ROM Drive: the CPU could also be fitted with a CD-ROM drive to write out data to save memory space and also to import some data if needed. It would be a 48 X Hewlett Packard HP (DC143B) Internal CD-ROM Drive which has a volume of ~ 68 in^3 and a weight of 800 grams [15].

- Communication: Like in the case of our previous design we stuck with W LAN for the purpose of communication on the sensor brick. The W LAN network adapter card that we selected was WUSB54G manufactured by linksys. This could be fitted to the USB port on the CPU. This Wireless G (802.11g) helped in setting up wireless networks with speeds of up to 54Mbps and was also compatible with 11Mbps 802.11b networks [18]. Since it was to be connected to the USB port on the CPU it would have operated on power drawn from the CPU.