Infrared technique and its application in science and engineering in the study plans of students in electrical engineering and electronics

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ABSTRACT: Thermography is a method that forms an image using infrared radiation of objects. Thanks to the rapid development of electronic devices and the new construction of equipment, thermography has become more popular. There are new applications for this technology in engineering, the army, natural science, medicine and other professional branches. Thermography application has been implemented in some engineering courses, sometimes in the first or second levels of study, as well as in postgraduate courses. In this paper, the authors present the main aspects of thermography theory and practice that are taught as a part of wider programmes of engineering and technology studies at the Higher Professional State School (HPSS), Tarnów, and AGH University of Science and Technology, Kraków, Poland.

INTRODUCTION

Thermography is a method that forms an image using infrared radiation of objects. Due to quick development of electronic devices and the new construction of equipment, thermography is becoming more popular. A number of courses are offered by infrared branches companies. Some examples of these are: Thermography Basics, Introduction to Indoor Electrical Surveys using IR Thermography, Introduction to Outdoor Electrical Surveys using IR Thermography, and Introduction to Residential Energy Audits using IR Thermography.

This paper presents the main goals in teaching the thermography technique to engineering students. Exemplar courses are taught in the Higher Professional State School, Tarnów, Poland (HPSS Tarnów) and AGH University of Science and Technology, Kraków, Poland (AGH Kraków).

At HPSS Tarnów, the University provides up to two hours of tutoring dedicated to infrared measurement and its application. It is offered to students in electrical engineering and material science as part of a 45 hour elective course, in the fourth semester. Another two hours of the course on infrared measurement and its application, make a part of a course on Microcontrollers and Embedded Systems delivered to students of the second year of IT. At Tarnów, the theory and application of IR techniques makes up a significant part of the course offered to Professional Energy Auditors. Students then learn about relevant hardware and software. At AGH Kraków, about two hours of the IR measurement and its application make up a part of the course of Diagnostics Systems and Expert Systems for students at the second level of IT study (previously a Master's Course in IT).

The thermography technique is very friendly and easy to understand. It is a strong and powerful tool not only for engineering, but also for other professional branches. After brief experience, students are able to use the device properly, correctly interpret the achieved thermographs, as well as prepare reports. A very important aspect of the teaching process is not only to understand the theory and practice, but also to interpret the results correctly.

HISTORY AND THEORY

Students learn the basics of IR theory developed over the last two centuries. The existence of infrared was discovered in 1800 by the astronomer Sir Frederick William Herschel. He decided to measure temperatures beyond the red portion of the spectrum and found that this region was the hottest. In 1929, the Hungarian physicist Kalman Tihanyi invented the first night vision camera for anti-aircraft defence in Britain. The first conventional IR camera (Evaporograph) was constructed in 1956.

The theoretical introduction to infrared techniques is based on an electromagnetic spectrum of infrared radiation (IR), blackbody theory, basics of radiometry, heat transfer, thermal measurements and fundamentals of infrared science. Students have to understand that thermograms must not be directly interpreted as temperature measurement of the observed objects. A thermographic camera (infrared camera) is a device that forms an image using infrared radiation. Infrared energy is just one part of the electromagnetic spectrum.

Infrared cameras operate in the wavelengths range of 750-14,000 nm. Any object that has a temperature above absolute zero (-273.15 degrees Celsius or 0 Kelvin) emits radiation in the infrared region. An IR spectrum is much wider than an optical spectrum. Heat transfer between the camera and the object consists of the emission, transmission and reflection. Transmission has a minimal influence (tends to zero), when emission (from the object) and reflection (off other objects) must be taken into consideration. If a point source radiates uniformly in all directions, and there is no absorption, then, the irradiance drops off in proportion to the distance from the object squared. In the observation of real objects, a number of factors must be taken into consideration. First, it is the thermal conductivity of the object. This value depends on the material (insulation tends to warm up slowly, while metals warm up quickly).

The difference in thermal conductivity in two different materials can lead to large temperature differences being observed. Emissivity also characterises the material; it is the object efficiency of infrared radiation [1-3]. Other important factors influencing observation are reflection and weather conditions [4]. Students also learn about the thermal resistivity factor that characterises the object. This is more important in electronic devices measurement [5].

To understand the role of each of the factors in IR observations, an introduction to the construction of IR cameras is necessary. Before that, some examples should be presented to students in order to illustrate the theory, as a comparison of thermograms of objects:

- with different thermal conductivity (or the same object insulated and without insulation);
- different temperature and the same emissivity;
- different emissivity and the same temperature;
- reflection of radiation;
- IR observations of the same objects under different weather conditions.

TEMPERATURE SENSORS AND ACCESSORIES

Depending on the time dedicated to a thermography course, different temperature measurement techniques and devices might be presented and compared. It should be pointed out that thermovision is not a temperature measurement. There are many quicker and more accurate measurement techniques. Contact temperature sensors and accessories that might be applied are thermocouples, thermistors, glass thermometers, bimetallic thermometers, semiconductor thermometers, liquid crystal, etc. Noncontact temperature sensors and imagers are radiation thermometers, thermal imagers, optical pyrometers, etc [5].

For the purposes of science and engineering, contact temperature sensors are usually applied. It is rarely pointed out in training courses organised or supervised by companies in the thermovision branch that infrared thermometers are reliable and very useful for single spot temperature readings. The biggest advantage of infrared cameras are rapid measurements of many points at the same time, comparison of several points in the one measurement and scanning of the surface (searching for hot-spots). What one can achieve from the infrared camera is a graph in which every pixel is a single measurement in the matrix of IR sensors [4][5].

THERMOGRAPHY CAMERA

Thermography cameras can generally be divided into two types: those with cooled infrared image detectors and those with uncooled detectors. The cooled infrared image detectors are mainly dedicated to science and research purposes as they provide superior image quality. Cooling is necessary for the operation of the semiconductor materials used. Uncooled thermal cameras use a sensor operating at ambient temperature, or a sensor stabilised at a temperature close to ambient. Uncooled infrared sensors are stabilised to an operating temperature to reduce image noise. This technology makes IR cameras smaller and less costly. However, their resolution and image quality tend to be lower. In uncooled detectors, the temperature difference at the sensor pixels are minute; a 1°C difference at the scene induces just a 0.03°C difference at the sensor. The pixel response time is fairly slow (milliseconds). Students can become familiar with several examples of the construction of uncooled infrared cameras, the electron scanning microscope imaging of different materials used in IR measurements and the microbolometer array (schema and its microscope imagine) [4][5].

INFRARED IMAGES

Images from infrared cameras tend to have a single colour channel, because the cameras generally use a sensor that does not distinguish between different wavelengths of infrared radiation. Colour cameras require a m ore complex construction to differentiate the wavelengths. Monochromatic images might be displayed in pseudo-colour, where changes in colour are used rather than changes in intensity to display changes in the signal (density slicing) [4]. For use in temperature measurement, the brightest (warmest) parts of the image are customarily coloured white, and the coolest parts are blue. The thermographic camera's resolution is considerably lower than that of optical cameras, mostly only 160x120 or 320x240 pixels. Students should compare several scales for IR images and decide which pictures are more readable.

APPLICATION OF INFRARED TECHNOLOGY

It is our strong belief that students should learn about the applications of thermal imaging as the technology is used in many fields. These include the military field, astronomy, fire fighting operations, search and rescue operations process monitoring, automotive applications, energy auditing of building insulation, detection of refrigerant leaks, medical and veterinary testing for diagnosis, pollution effluent detection and aerial archaeology [6-13].

As about 35% of all industrial fires are caused by electrical problems, an important application of IR imaging technique is for high voltage installations inspections. Because of the risk of electric shock, high magnetic and electric field intensity, highness, etc, many points of inspection are not easily accessible. Hence, thermography is the safest and most efficient technique to support such inspections.

In high voltage installations, when electrical current passes through a resistive element, it generates heat. Examples of failures that might be detected with thermal imaging include overheated, incorrectly secured connections, oxidation of high voltage switches and insulation defects. In low voltage installations and equipment (electric and electronic engineering application), this technology can be used to detect poor connections and internal damage, high resistance connections, corroded connections, internal fuse damage, internal circuit breaker faults. Generally, the hotspot indicates a short circuit that can potentially start a fire.

In mechanical installations, IR observations can be applied as prototype testing and in mechanical components and installation monitoring. Critical issues can be detected, such as lubrication problems, misalignments, overheated motors (internal winding problems, etc), suspect rollers, overloaded pumps, overheated motor axles, etc. Typically, when mechanical components become worn and less efficient, the heat dissipated will increase. The temperature of faulty equipment or systems increases rapidly before failure.

Further, pipeline faults that can be detected include leakage in pumps, pipes and valves, insulation breakdowns and pipe blockages.

Advanced optics and sophisticated software interfaces continue to enhance the versatility of IR cameras. The thermal camera is more often applied to non-destructive testing methods of new materials and technology (in materials engineering, electronics, etc).

THERMOGRAPHY SAFETY

Thermography safety should be emphasised in the course. Ergonomic design of the equipment, proper use and safety rules during IR monitoring and observation of the objects are part of the course. Users have to remember that observations with IR camera are usually done in a dangerous environment, where other techniques are not appropriate. The danger for the camera operator might be hot elements, very cold elements, high voltage, machinery in motion, intensive electric and magnetic fields, chemicals, etc. The laser pointer in the camera is then very useful as it eliminates the tendency to finger-point at objects, which can be dangerous in many industrial settings.

EXERCISE - PARAMETERS OF AN INFRARED CAMERA

Students have to learn how to use a given thermal camera. They should know about the camera's resolution and thermal sensitivity. To optimise the image quality they should learn about the camera's functions and set factors such as ambient temperature, humidity, material emissivity, etc, correctly. Students learn to take pictures of specified objects, making notes and comments. Among the things that should be observed are objects with different temperatures, different materials, and objects when cooling or heating. There should also be observation of examples of machinery, electrical equipment and people.

For indoor observations, it should be pointed out that there is reflection from the other objects' radiation, and warm ambient reflection, air conditioning or heating or cooling systems influence the observed objects. *Calibration tape* can be used to ensuring correct emissivity and reflection (a piece of tape with a known emissivity). Students observe with IR camera microcontrollers, motors, air condition, electrical equipment, humans, and other objects. Some outdoor observation of objects such as buildings, machinery, etc, could be done. It should be pointed out that the sun's reflection, ambient reflection, rain, wind, etc, influence the object's radiance.

Further, students might obtain knowledge of a special camera's additional functions, such as correction of emissivity and reflection, manual span and level correction, digital camera incorporated, LED built-in light, picture in picture (to combine images from the digital camera and the thermal imaging camera), thermal fusion (to combine these two images smoothly by setting temperature parameters within, which thermal data is shown and outside which the digital photo is shown), laser pointer, interchangeable lenses, image format, speech and text comments, GPS location, compatibility with external test and measurement tools and wireless connectivity. Figure 1 shows some images that were obtained during students exercises.

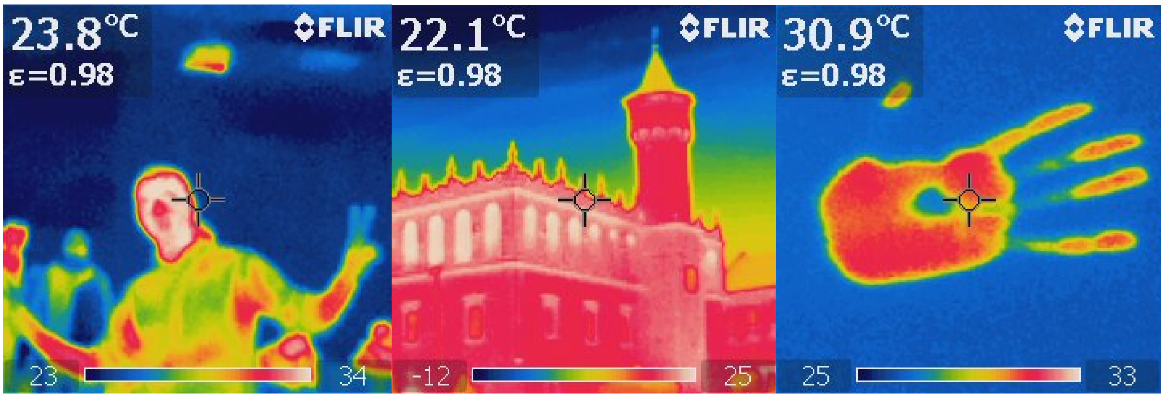

Figure 1: Examples of termograms taken by the students in May 2011 (HPSS Tarnów).

EXERCISE - INTERPRETATION OF INFRARED PICTURES; RECOGNITION OF COMMON MISTAKES AND MISINTERPRETATION

Students have to learn how to use software. Analysing thermal images and creating comprehensive inspection reports are important tasks. Students should work on the previously obtained pictures. They learn how to edit pictures using software, optimise the scale (colour or shadows), recognise and compare materials, and set up the correct material factors (such as emissivity, etc). The comparison of observations is then carried out.

The most common mistakes to be recognised include misinterpretation of the surface temperature due to too high or too low ambient temperature, badly determined ambient humidity, badly determined object material (emissivity), misinterpretation of the reflection, and overcooling or overheating of the observed objects. Airflows cool down the surface material, lowering the temperature differences between hot and cold areas. Heating systems create temperature differences that can cause misleading thermal patterns. Cool air flows from ventilators or air conditioning systems can have the opposite effect, cooling down the surface material, while the components below the surface are hot, which may cause potential defects to remain undetected.

Outdoors, weather factors that must be taken into account include sunlight, wind and rain. The last is a factor that can render thermal imaging inspection useless (it cools down the surface material) as evaporation of the water cools down the surface material. This can lead to misleading thermal patterns. The sunlight caused patterns should not be mixed up with patterns generated by heat transfer. Further, it should be noted that wind and airflows cool down the surface material, lowering the temperature differences between hot and cold areas.

Students should learn at least the operation of the basic software applicable to the image interpretation and prepare reports. They might also become familiar with more extensive software packages, with features that include flexible report page design and layout for customised reports, powerful temperature analysis tools (multiple spots, areas, temperature difference measurement), triple fusion Picture-in-Picture (movable, sizable, scalable), trending functionality, formula creation using thermal imaging measurement values, play radiometric sequences directly in the report, search functionality to quickly finding images for report, panorama tool for combining several images to a large one.

CONLUSIONS

Based on the experience gained from the teaching/learning process, one can draw several conclusions:

- Infrared technique is a powerful tool for engineering and natural science. Because of industry demands, it should be incorporated in modern curricula and study programmes.
- The basics of infrared technique are taught at the Higher Professional State School, Tarnów, Poland (HPSS Tarnów) and AGH University of Science and Technology, Kraków, Poland (AGH Kraków) to engineering students (first level of study, second level of study and professional courses).
- Lectures consist of the physical background of thermography, temperature sensors and accessories, thermography camera constructions, analysis of infrared images, as well as possible application of infrared technology.
- Exercises done by students are dedicated to the technique application. Students take infrared pictures and analyse them.
- Most common mistakes that occur during the exercises is overlooking the ambient temperature and reflection.

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