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Pipeline Monitoring Using Thermal Cameras

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***Abstract*: This document is a research proposal stating the use of thermal cameras for pipeline monitoring on a process plant instead of the use of conventional sensors.**

***Keywords*: Near infrared (NIR), Shortwave infrared (SWIR), Midwave infrared (MWIR), Longwave infrared (LWIR), absorbed (α), Transmitted (τ), Reflected (ρ), Emissivity.**

1. Introduction

Infrared radiation was originally discovered in 1800 by Sir Frederick William Herschel (1738-1822), who is also famous for discovering the planet Uranus as well. Infrared radiation is a part of the electromagnetic spectrum, and its name originates from the Latin word infra, which means below. The infrared band lies below the visual red light band, as it has longer wavelength. The infrared wavelength band is broad and is usually divided into different bands based on their different properties: near infrared (NIR, wavelengths 0.7–1m), shortwave infrared (SWIR, 1–3 m), midwave infrared (MWIR, 3–5 m), and longwave infrared (LWIR, 8–12 m). When interacting with matter, electromagnetic radiation is absorbed (α), transmitted (τ) and/or reflected (ρ). The total radiation law states that $1 = \alpha + \tau + \rho$ where α, τ, ρ [0, 1]. In addition, an object's thermal energy can be converted into electromagnetic energy, called thermal radiation. All objects having temperatures above absolute zero emit thermal radiation depending on temperature and material. An object defined as a black body is an opaque and non-reflective object that absorbs all incident radiation (α= 1). Black bodies do not exist in nature, but are commonly used as a reference. Emissivity (£) is defined as the ratio of the actual emittance of an object to the emittance of a black body at the same temperature. Further, Kirchhoff's law states that α = £, i.e., £ = 1 for a black body. Since emissivity is material dependent hence is an important property when measuring temperatures with a thermal camera.

2. Description

A. Thermal Imaging

Thermal images are visual displays of measured emitted, transmitted and reflected thermal radiation within an area. When presented to an operator, color maps are often used to map pixel intensity values in order to visualize details more clearly. Due to multiple sources of thermal radiation, thermal imaging can be challenging depending on the properties of the object and its surroundings. The amount of radiation emitted by the object depends on its emissivity. In addition, thermal radiations from other objects are reflected on the surface of the object. Therefore, it is also important to know the reflectivity of the object. The amount of radiation that reaches the detector is affected by the atmosphere. Some of the radiation is transmitted, absorbed, and even emitted from the atmosphere itself. Moreover, the camera itself emits thermal radiation during operation. In order to measure thermal radiation and thus temperatures as accurately as possible, all these effects need to be considered. At short distances, atmospheric effects can be disregarded. Thermal cameras these days can use either Uncooled or Cooled sensors to detect electromagnetic radiation.

The infrared spectrum constitutes only a part of the whole electromagnetic spectrum (as shown on the visual) and in its turn has three effective ranges depending on the wavelength:

- Long-Wave IR (LWIR) (7.5-14m) – typically used by uncooled IR cameras;
- Medium-Wave IR (MWIR) (3-5m) – typically used by cooled IR cameras;
- Short-Wave IR (SWIR) (1-3m) – typically used in active illumination night vision technology

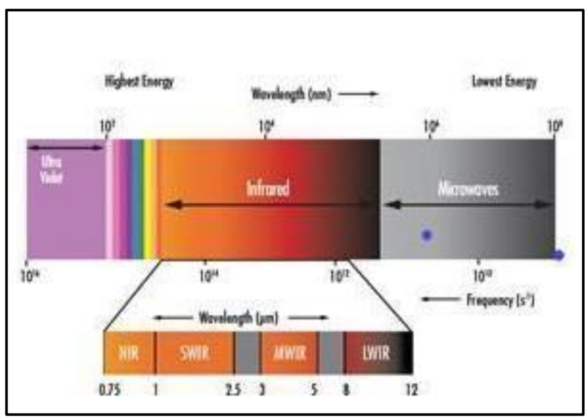

Fig. 1. Electromagnetic Spectrum

B. Cooled Cameras

The compact cooled thermal imager constitutes the imaging sensor, which is highly equipped with the cryocooler unit. In this cooled thermal imager, the minimized temperature of the sensor is used to reduce the thermal noise power range to create the image formation. This cooled version of thermal imager helps to reduce the temperature of the sensor below the temperature of the cryogenic limit. The cryocoolers inbuilt in the cooled thermal imager is useful against the mechanical tolerance, strong sealing over helium gas and wear out capability. The cooled thermal imager is considered as the high sensitive camera device which helps to estimate the difference.

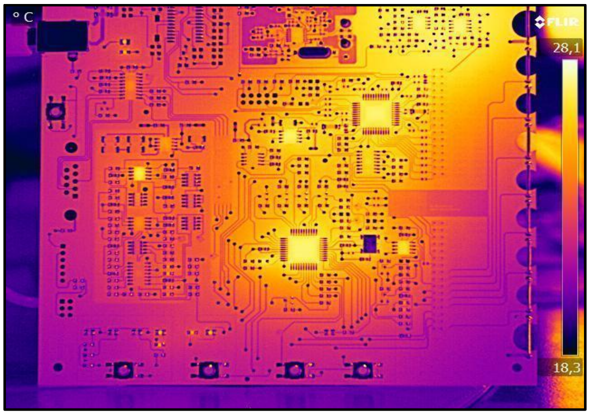

Fig. 2. Image from Cooled Camera

The cooled thermal imager includes the thermal contrast of high range which is used to determine the differentiation of objects to that of its background to estimate the hot spot and cool spot of the targeted image. It is designed to overview the long wave infrared and mid-wave infrared band of the spectrum imaging.

3. Design

Thermal imaging has several industrial applications but, let us consider thermal imaging used for the analysis of the piping that is involved in a process plant. Consider a visible pipe with a diameter >40inches. Plant monitoring involves measurement of various parameters. But among all of them one of the most important process variables is temperature. Thermal imaging allows us to make a very accurate and precise measurement of temperature. If we use the conventional thermal sensors for the same purpose, then we usually face constraints such as selection criteria according to the operation ranges, only limited to point measurement, requirement of multiple sensors for the entire plant monitoring, calibration errors, etc. To overcome these constraints, we propose the deployment of thermal cameras. They are capable of measuring a wide range of temperature over a larger proximity, hence they can be installed to measure the temperature of a large length of the pipe wherever they are focused with a coloured indication as well as display of digits wherever a temperature change occurs. An important point to note here is that, all the temperature variations related to the pipe are indicated as well as recorded simultaneously and continuously. Along with temperature measurement, the other important application of a thermal imaging camera is that along with temperature measurement, it also detects leaks present in the pipe. The extent of minuteness of the leak that the camera can detect depends upon the resolution of the camera. This plays a vital role in the safety of the plant as well as its workers. The reading taken by the camera for the temperature of the pipes at every point can then be transmitted to the elco board directly of D.C.S. architecture.

Accordingly, an appropriate action can then be taken as per the received signal. To make use of a single thermal camera for the entire piping assembly or use multiple cameras at various positions for the piping assembly depends entirely on the user. The count of cameras that would be required for the process is dependent on various aspects such as diameter of the pipe, number of pipes, their position, etc. The cost of thermal cameras for measurement of process variables might appear to be more as compared to the conventional thermal sensors, but, one must also consider that multiple variables can be measured by a thermal camera. Along with that, a single thermal camera can be used to monitor a comparatively large portion of the plant if appropriate infrastructure is provided.

4. Implementation

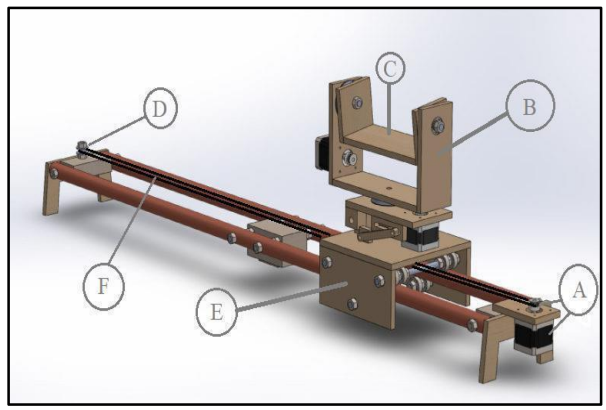

Fig. 3. Assembly

- A-Stepper motor
- B- Camera mount
- C- Mount for adjusting camera's orientation
- D- Roller
- E- Main mount
- F- Belt

In this design, a design for the mounting the Cooled thermal camera is shown above just to give an idea to use the thermal camera to monitor the process plant at a certain position or at varying positions. The entire mechanical assembly can be made of stainless steel or any other material as per the application and ambient conditions. Also, proper shielding needs to be provided to the electrical components as per the application. This assembly enables the user to mount the camera in a steady position and move it as per the requirement of the user. The length of the columns can be kept as per the user's choice. In this paper, we have suggested this assembly to be installed in a rectangular shape like a fence around the portion of the process plant that we desire to monitor. But, the assembly can be installed in any desired orientation so as to cover the maximum view of the piping assembly whose temperature and other factors we desire to monitor. The camera can be mounted at position A. The section B is optional if it is desired that the camera's orientation needs to be changed along a vertical axis. A belt will be installed between positions A and D. The belt will be connected to the main mount mid-way. This arrangement makes it possible to move the main mount. The stepper motor at A should be preconfigured to set the speed at which it will rotate as well as the direction in which it will rotate. A PLC (Programmable Logic Controller) based system can be installed where the PLC is configured with a timer circuit. This means that the PLC will transmit the signal to the motor to rotate in a certain orientation for a certain time which will make the belt rotate between points A and D. Also, this PLC command will be sent after a certain time interval. The belt being connected to the main mount pulls the entire camera mount when the stepper motor rotates. The direction in which the camera moves can be decided by the orientation in which the motor rotates i.e. clockwise or anti-clockwise. This will result in the thermal imaging camera to automatically move to specified locations after every set time interval. The need to change the camera's position may arise if the target whose image needs to be captured is out of the camera's frame or if it is getting blocked by some other object.

Factors for selection of thermal cameras:

- Infrastructure
- Pipe Diameter
- Pipe Length
- Number of Pipes
- Resolution (1266*1010 px)

5. Conclusion

The installation of the camera as per the above mentioned design will move the camera to the desired positions. This eliminates the installation of a substantial number of the conventional sensors. Additionally, when it comes to maintenance of the sensors, the aspect must be considered that it will prove much efficient to service one component (thermal imaging camera) rather than service several components (conventional sensors).

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