Ice Detection Experimentation Setup Using Infrared and Active Heating

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***Abstract*—The paper shows the possible implementation of Infrared (IR) ice detection technique. The experimental setup is implemented keeping in view of the marine icing phenomena over the ships and offshore structures. The detection mechanism is unique from the passive IR detection by introducing the active heating concept. The intervention of the active heating information inside the IR ice detection system will be able to improve the system's detection capability and disseminate the valid information at user interface level. The experimentation shows valid detection of ice and no/ice conditions based on consistent temperature gradients.**

Keywords—icing; detection; infrared; heat; surface interface;

I. ICING AND INFRARED DETECTION

In the challenging environment such as below zero temperature conditions, ice accretion can occur at a rapid pace. This can adversely affect the marine operations in cold climate. Taking into account for such conditions, ice detection can be useful for the ice mitigation and removal upon the marine and offshore structures. Various techniques exist in the literature to detect the icing that exploit its physical or electromagnetic properties [1]. The parameters measured by these ice detectors includes the mass, rate and liquid water content [2]. Generally, the atmospheric icing is detected from most of these detectors. The other type of icing is marine icing that is a safety concern in marine operations inside the cold regions. Marine icing is different in nature from the atmospheric icing. It involves sea spray influence that is produced from the collision of the waves upon the structure and wind that shear the high wave crests [3, 4]. The subsequent sea spray generated by the collision of waves and its shearing travels in the air and freezes on impact with the ship superstructure or offshore structure elements. If this type of icing continues to occur for a longer duration, it can cause an increase in ice loading which could be hazardous if not mitigated in time. Such icing conditions are also hazardous for human operations. In this case, ice detection can be useful to assist the anti/de-icing process.

The techniques mentioned above for ice detection include point and area detection of ice. In the marine operations, remote detection of icing could be effective as it can assist the detection of a larger surface area. Remote monitoring of ice upon surfaces was tested in aviation industry where icing on aircraft wing was observed using infrared cameras [5]. The effectiveness of infrared application in icing for the marine environment needs to be investigated. Apart from the aviation industry, infrared remote monitoring is being used in various industrial applications where the temperature monitoring is critical on the larger surface area. Acquiring thermal signature from infrared devices gives the advantage to analyze temperature profiles of the complete system without any direct contact. Studies have shown that infrared cameras can be utilized to monitor the cold objects at low temperatures [5]. Recently, in the marine operations, specific infrared cameras are currently being used to detect the floating sea iceberg, which indicates the possible applicability of infrared devices in the marine environment.

In this paper, effort is being made to show the infrared experimentation setup for detection of marine icing. Lab-setup is explained taking into account of the anti/de-icing techniques used in ships and offshore structures in marine environment. Section-II explains the setup components including an infrared camera, heating elements, surface material, control and monitoring systems. Setup components details are not specified as the experimental setup for ice detection is preliminary in nature, therefore, can be modified for improvements. Section-III explains the experimental setup and section-IV shows the results and discussion regarding thermal gradients at ice/no-ice conditions. The paper concludes in section-V showing the technique's effectiveness towards ice detection in the marine environment.IR Thermography and Thermal Signature Detection at Low Temperatures

II. SETUP COMPONENTS

A. Infra-Red (IR) Camera

IR camera operates with the incident IR beam. IR light is electromagnetic radiation that has a longer wavelength as compared to the visible light. It has a spectral range starting from the edge of the visible red light from 0.74μm to 300μm. The infrared spectral band is generally sub-divided into four sub-bands; near infrared (NIR) (0.75–3μm), medium wavelength infrared (MWIR) (3–6μm), long wavelength infrared (LWIR) (6–15μm) and very long wavelength infrared (VLWIR) (15–1000μm) [6]. IR camera working principle is based on the thermography imaging. The major components of the IR camera are a lens, detector, video processing electronics and user interface control as shown in Figure 1. The IR camera operates with the incident beam of light focusing upon the detector by the lens. The detector contains the IR sensitive elements arranged in the array called

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focal plane array (FPA). These are IR sensitive elements and miniature in size (micro- meters). The number of elements inside the array determines the resolution of the IR imagery produced by the camera [7]. The processing electronics interprets the detector signals into the infrared imagery. The processing electronics also controls the parameters of the captured imagery. The sets of commands can be given to processing electronics via user interface. Currently available IR cameras generally include a user interface software to compute the parameters such as scene temperature, calibration, external trigger input and imagery recording. The calibration is often required to read out the correct temperature across the captured scene.

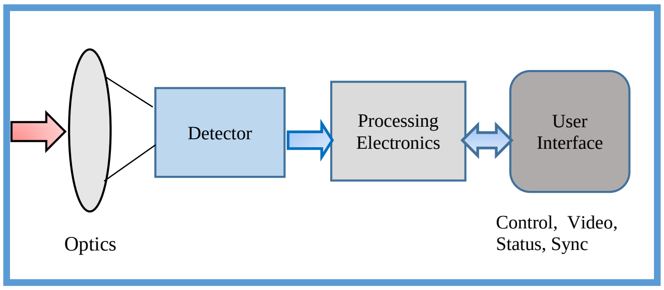


Figure 1. IR Camera working principle

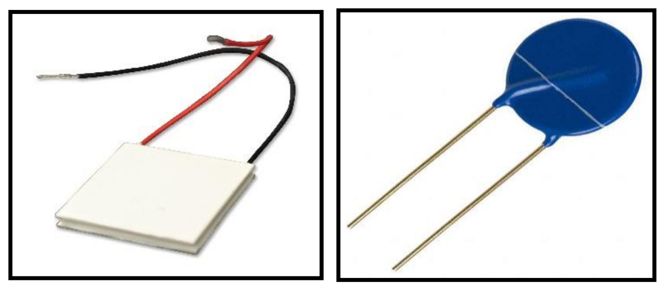
Cold temperature scene can also be observed with the help of IR camera. The observation of icing surfaces from IR thermography has been reported in literature [8] but no significant literature is available of marine ice detection in cold regions. The application of IR thermography in ice detection for ships and offshore structures can be experimented to evaluate its capability.

B. *Heating Elements*

IR thermography for ice detection can be challenging when uniform scene temperature is observed. The thermographic profile of the cold object and the scene temperature might be the same in some cases that could lead false detection of ice. Furthermore, the reflectivity of the ice under certain conditions can indicate a false temperature captured by the IR detectors, which requires calibration. Normally calibration is done with the known objects temperature, which could be a difficult task to perform repetitively during the field operations in the cold harsh environment. The false detection problem from IR thermography can be minimized if the active heating mechanism is introduced underneath the platform or structure upon which ice is accreted. The heating elements will perform the major role in generating the known heat signature when the ice is accreted over it. The heating elements utilized in the experimentation setup could be electro thermal based with the strong heat generation capacity. The size of the heating elements should be minimum and compact so that they could be arranged in the form of arrays as discussed in section-III. Few examples of heating elements that could be tested as an active heating source for the experimentation are Peltier thermoelectric modules (Figure 2a) and Thermal resistive elements such as positive thermal coefficient of resistance (PTC) as shown in Figure 2b

Peltier thermoelectric modules are solid state devices based on thermoelectric heat pump theory as they behave like a heat pump and transfers the heat from one side of the device to the other side. As the modules withdraw the current, one side becomes immediately hot and another side becomes cold. The hot temperature can reach up to hundreds of degrees (C^o); similarly, cold side acquires negative temperatures very quickly. On the other hand, the positive thermal coefficient of resistance (PTC) heaters works on the principle of resistive heating where resistance increases upon heating. PTC devices can provide the high-temperature range up to 150^{o}C or more depend upon the type of resistive material used and current rating.

These elements discussed are commercially available in miniature sizes (few centimeter) and can be controlled with the DC or AC powered control circuitry. The control mechanism of these heating elements is significant for the experimentation that will be used with IR user interface capturing mechanism



a. Peltier thermoelectric element [9] b. PTC thermal resistor element [10]

Figure 2. Heating elements

C. *Surface Interface*

The surface interface is the overlying material above the heating elements arrangement. The purpose of the surface interface is to supply heat through conduction. The heated elements underneath the surface transfer the heat to the icing layer accumulated on the overlying surface. Efficient conducting materials can be used as surface interface materials for the experimentation process. Metals for instance aluminium, iron, copper etc. can be considered as the interface materials.

D. *Control Module*

The control module consists of electronic circuitry used to control the heating elements. This module recognizes the input from the user interface and drives the heating elements through its digital output lines. The control module executes the image capturing based on producing the external trigger signal. This trigger signal drives the infrared camera to capture the image for that instance. The final imagery is displayed through the imaging interface for temperature profile recording. Thus heated elements on/off signals are generated by the control module that are in accordance with the IR imagery profile.

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E. User Interface

The human interface in the experimentation process is the mutual interface of IR imagery analysis software and control module circuitry. The observation of the IR camera software will produce the thermal signature and temperature profiles of the icing. Control module will produce the operating cycles of the heating elements to produce the imaging profile. The resultant imaging is then analyzed to evaluate the captured scene.

III. EXPERIMENTAL SETUP

The experimental setup for marine ice detection comprises of the components discussed in the section-II. The IR camera of MWIR range is used at angle normal to the icing surface. This was done to avoid any possible reflections that could lead to false temperature detection. The IR resolution of the camera used in the experiment is 320 × 240 pixels with the temperature sensitivity of 0.05^0C. The distance of the IR camera from the icing surface was kept small (60 cm) such that the surface image fits into the camera frame. The reason behind was to keep the frame coordinates same for analysis and to avoid camera zoom during experimental observations on the user interface. Most of the commercially available IR cameras include the user interface package. The complete proposed setup is shown in Figure 3.

The active heating control in the IR ice detection is provided by the control module. The control module is responsible for controlling the power on and power off timings of the heated elements. The heating elements discussed can also be used as deicing agents. Integration of the camera's user interface with the control module helps to synchronize the captured scene with the control mechanism. The infrared energy of a certain temperature is released when control module drives the heating elements. The individual selection of the heated elements provides the flexibility to warm a particular area. This helps the IR energy to be captured at the desired locations. The IR signature captured can be evaluated in the IR user interface software to validate the presence of ice.

The operating mechanism of the experimental setup starts with the capturing of the IR frame without turning on the heating elements. Once the image has been captured the control module turn on the heating elements and second IR frame is captured. The images are saved and post processed to evaluate the results. The post processing of the images is performed with the patented software tool that is part of the user interface. The post processing included the frame calibration, temperature profile extraction and plotting the results.

The working principle of an IR camera is based on thermography imaging. The major components of the camera are lens, detector, video processing electronics and user interface control. The incident beam of light is focused by the lens upon the detector. The detector contains the IR sensitive elements arranged in the array called focal plane array (FPA). These are IR sensitive elements and miniature in size (micro-meters). The resolution of FPA determines the resolution of the IR imagery produced by the camera. Many IR cameras available have user interface to calculate the scene temperature along with imagery recording software. Calibration is often required to read out the correct temperature across the scene that is captured.

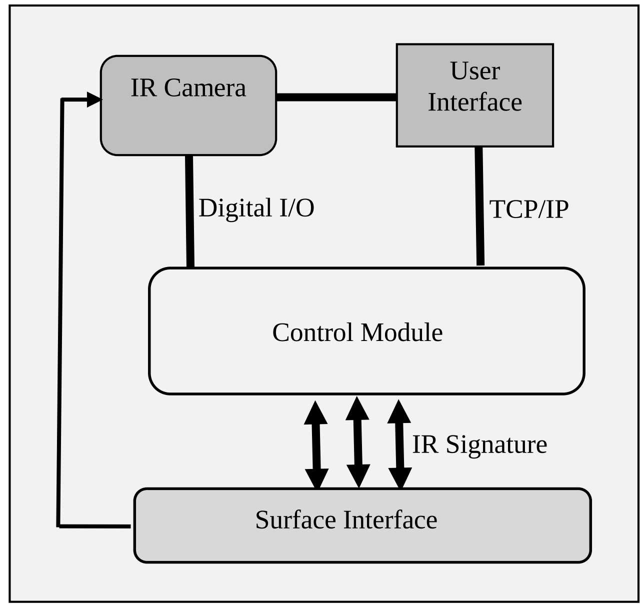

Figure 3. IR ice detection setup with active heat signature

IV. RESULTS AND DISCUSSION

The experimentation was performed to observe the infrared signature of pure ice and water droplets on a heated surface. These experiments were performed at room temperature. The heated elements were operated by the control module. The top of the surface interface was covered with pure ice. The pure ice sample was prepared in a round shape. The surface area of pure ice sample was $55cm^2$ with the thickness of 0.6 cm. This ice sample was placed on the heated area of approximately 64 cm^2. The heated elements were operated above 100^0C for a short period of time (20-30 seconds). The observations were made on the surface temperature from 23^0C to 115^0C. The duration to reach the peak temperature was approximately 25 seconds. The IR user interface was used to record infrared signatures of the ice sample. These isothermal profiles are shown in figure 4. The temperature profiles across the cross-sectional area of ice sample were observed from the isothermal images that is shown in the figure 5

The temperature profiles of the ice sample show consistent temperature recordings from 1.64^0C to 2.1^0C (figure 5) at the interface temperature of 23^0C, 80^0C, 110^0C and 115^0C. The presence of ice can be asserted with the temperature recordings around 0^0C. In the case of non-icing conditions above the surface interface, temperature profiles must be on the higher scale.

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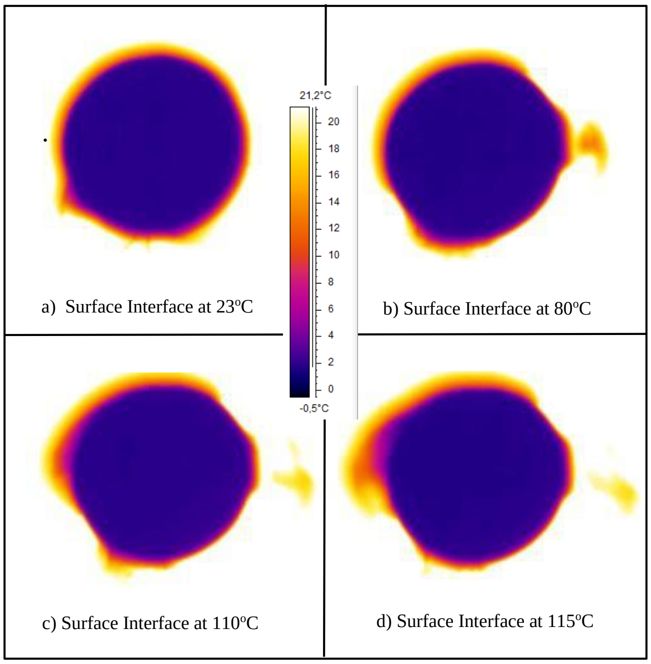

Figure 4. Pure ice iso-thermal signature on the surface interface

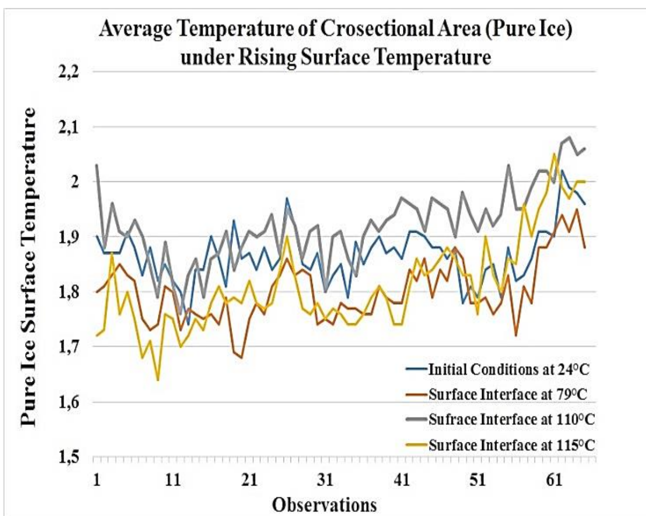

Figure 5. Pure ice cross sectional surface temperature over known heated interface

The other noticeable results were obtained by observing the water droplets of different sizes over the surface interface as shown in figure 6. The isothermal infrared signature shows the presence of droplets in contrast with the rest of the surface. These observations were recorded at the surface interface temperature of 23^{0}C, 38^{0}C, 55^{0}C and 80^{0}C. The average temperature recordings of the small and large water droplets were performed (figure 6). The water droplets temperature increased as expected and a significant difference in the temperature was observed between large and small water droplets (figure 6).

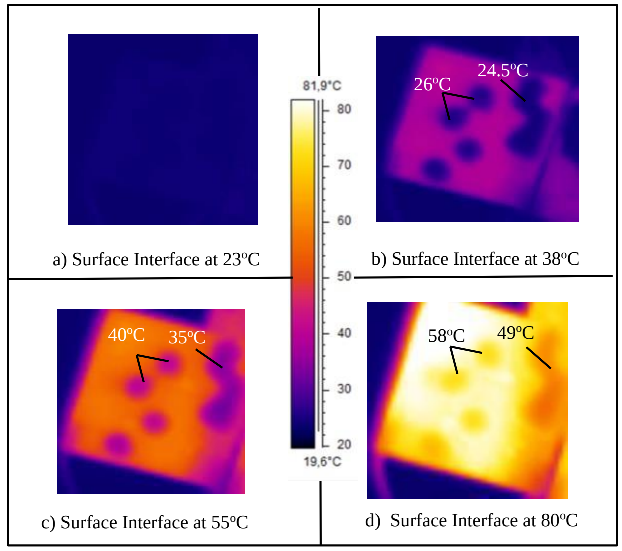

Figure 6. Water droplets isothermal signature on the surface interface

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