Field Study of Ice Detection on Structures Using Passive Thermal Infrared Imaging

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***Abstract*--Different techniques have been used by researchers to detect ice accretion on structures, but most of these techniques detect ice on a particular (point) location and detecting the ice on large surface areas is still a problem. This paper describes a passive thermal infrared-based ice detection technique for large surface areas. A field study has been carried out to detect ice accretion on various large structures such as roads, bridges, communication towers and fishing vessels. Results from this preliminary field study show that passive thermal infrared-based non-intrusive ice detection method can be a promising way to detect ice on large surface areas, where typical point based icing sensors do not work effectively.**

Keywords- Atmospheric ice detection; Structure; Passive thermal infrared; Temperature distribution.

I. INTRODUCTION

One of the difficulties of atmospheric ice detection on structures is how to accurately detect and analyze the intensity of accreted ice on a surface. Most ice detectors are point devices and measure required icing parameters only at one particular location, while the interest of operators is often to detect ice accretion over a large surface area. At the same time, ice detector technology must not interfere with the ice accretion process, so that the measurements are accurate, nor should it be affected by the icing event itself, which is one of the problems with the present point based ice detection methods. Generally four ice detection technologies; imaging, remote, conformal and probe are used for annunciating the presence of ice, automatically triggering ice protection technologies and indicating whether ice has been removed or not [1]. A system based on the processing of thermal images acquired in the infrared spectra can be a possible way to monitor the ice accretion in a non-intrusive manner, while covering all these areas of interest.

The infrared spectrum lies below the visible band. Infrared (IR) imaging can be divided into two main categories: *active imaging and passive imaging*. Active imaging techniques use artificial IR lighting source to illuminate the target image where icing might be present, then an infrared sensor collects the reflecting signal. A plethora of successive images over a number of sub-bands are collected, which are then processed to determine whether or not ice is present. One example on the active method is the "*Ice Camera*" which has been developed by MacDonald, Dettwiler and Associates Ltd. (MDA). The "Ice Camera" system utilizes a multi-spectral infrared camera that detects both ice and water. It employs a reflectance spectroscopy technique to detect ice of 0.5 mm thickness or above [2].

Passive thermal infrared image captures the naturally radiated infrared from the target to construct an image. In this technique, a thermal image is constructed using a *Focal Plan Array* (FPA) sensor that captures the radiated IR energy from the object. The FPA is designed to sense a certain band of IR radiation depending on the application for which the thermal image camera will be used. Every object in the world emits thermal radiations, which are mainly the function of object temperature and surface emissivity. When the object's temperature increases, the radiation also increases. Thermal imaging devices capture these thermal radiations and allow one to study variations in surface temperature. During ice accretion process, the region where ice accretion occurs becomes warmer than the surrounding surface due to release of latent heat of fusion while water freezes. In case of an area already covered with ice, the iced surface will have low temperature as compared to the un-iced surface area. By measuring the intensity of thermal radiation from the surface material and emissivity, it then become possible to infer the surface temperature in icing conditions. For thermography analysis *emissivity of the object, reflected apparent temperature, distance between radiated object and thermal camera, relative humidity and atmospheric temperature* are the important parameters that need to be taken into consideration for reliable results [3]. Very little work has been reported to detect the ice on surface using thermal infrared techniques, as most work in this regard has been done using the active infrared approach. Adam et al.[4] used the passive thermal infrared technique to investigate the atmospheric ice accretion on helicopter rotor blade, where a prototype detector system was built consisting of a single point infrared pyrometer. The characteristic chord wise temperature distribution was observed during the icing event. Virk & Ghani [5] conducted a lab based experimental study to detect ice on wind turbine blades using a passive thermal infrared approach.

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The paper describes the preliminary field study to analyze the non-intrusive passive thermal IR based approach for detection of ice on large structures in cold regions. The remainder of the paper is structured as follows. Section II covers the field measurement setup used for this study. Section III describes the results & discussion of the field measurement study. The acknowledgement and conclusions close the article.

II. FIELD EXPERIMENTAL SETUP

The field study was carried out in the northern part of Norway during winter 2013/2014, using simple experimental setup consisting of a very long wave (17 µm) thermal infrared camera (*FLIR A615*), data logger, image processing software (IRControl) and a laptop computer. Analyses were carried out for different structures (*bridge, communication towers, roads and fishing vessels*). The thermal infrared images were processed to measure the surface thermal signature and these surface temperature distributions helped in identifying the ice distribution along surfaces of these large structures. Figure 1 shows a schematic overview of the experimental setup used for this field study.

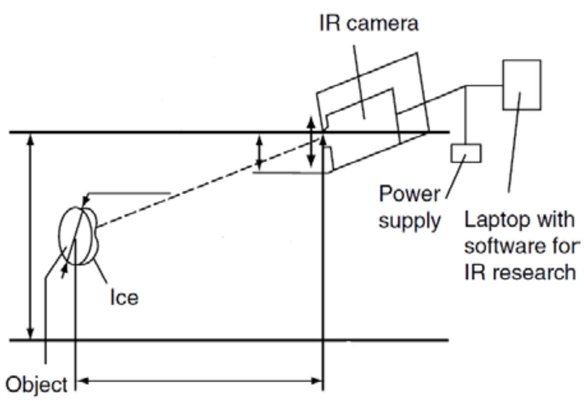


Figure 1. Schematic overview of field experimentation setup

In this setup, the IR camera measures infrared radiation in a specific spectral range. The radiation originating from structural surface is directly related to its temperature and makes it possible to calculate the temperature distribution on structural surfaces based on the radiation measured. This information was reproduced as an image. The radiation measured from IR camera is not only a function of temperature, but also the emissivity of the measured object. Emissivity is often not uniform across the entire surface of the object. IRControl software used in this study has the capability to measure emissivity. A locally generated emissivity map is calculated and recorded. Other factors effecting the IR radiation like reflected ambient radiation, object distance, relative humidity and the atmospheric damping has also been compensated within IRControl software used in this study for IR image processing.

III. RESULTS & DISCUSSION

A. *Road Bridge*

In recent years, the relevance of ice accretion for wind-induced vibration of structural bridges has been recognize as a safety hazard. Two main topics of concern in this regards are, 1) icing on road surface of bridge, 2) icing on bridge structural components mainly on cables. As an overall, ice accretion on bridge effects both static and dynamic stabilities due to added mass effects of accreted ice and changes in wind induced aerodynamic effects. In addition, ice chunks falling from bridge members/cables can also cause traffic accidents, direct damages to passing vehicles and generally place human safety at risk [6].

A field study has been carried out to detect the ice accretion on a hanging bridge structure by using passive thermal IR approach. Figure 2 shows the results of surface temperature distribution along each selected location of the bridge.

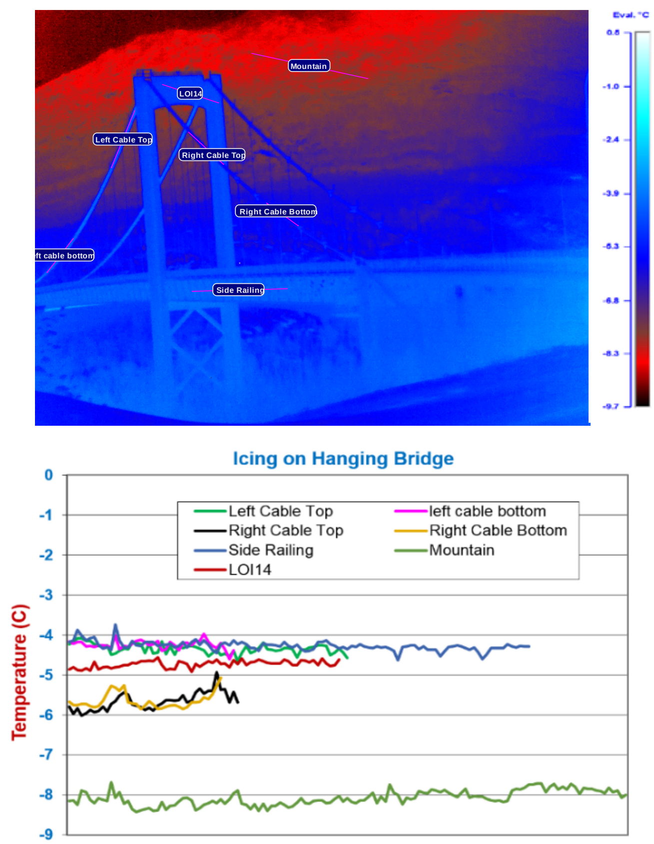


Figure 2. Surface temperature distribution along different sections of iced bridge

Surface temperature distribution at seven different locations was analyzed and compared with the visual observations of iced areas. Results showed a significant variation in surface temperature distribution along these selected locations. The lowest surface temperature was found along the top end of the bridge, where ice was accreted. More ice was found on windward (right) side of the bride. Ice detection by IR thermal images was also found in agreement with the visual observations. A systematic application of this approach can help to routinely monitor the ice accretion along bridge and avoid any possible incidents effecting the safety of the bridge structure and pedestrians.

B. Road Surface

In regions with subzero temperatures, severe road conditions are common, therefore a good knowledge of the road conditions is important for performing effective and environmental friendly safe road maintenance. Water freezes to ice causing a drastic decrease of road surface friction, which can lead to an increase in the possibility of traffic accidents [7]. The importance of finding the point at which a wet road surface will freeze implies that a correct monitoring of road surface is necessary. The limitations of existing technology is not the ability to get qualitative data at single point, but to get data that represents the actual road conditions over a large surface area. It is difficult to accurately estimate the road condition from a single point freezing point sensor, therefore additional efforts are required to better detect the presence of ice and differentiate between different types of accumulated ice on the road. There is a good potential in non-intrusive infrared (IR) based technology for monitoring the road weather conditions in cold and icing conditions. This technique can give detailed information about the top surface temperature of the road, which is crucial for finding possible icing locations.

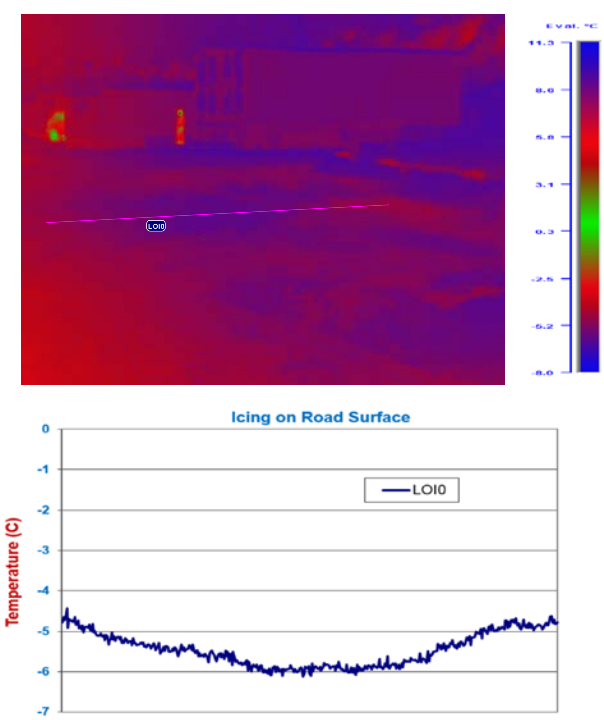
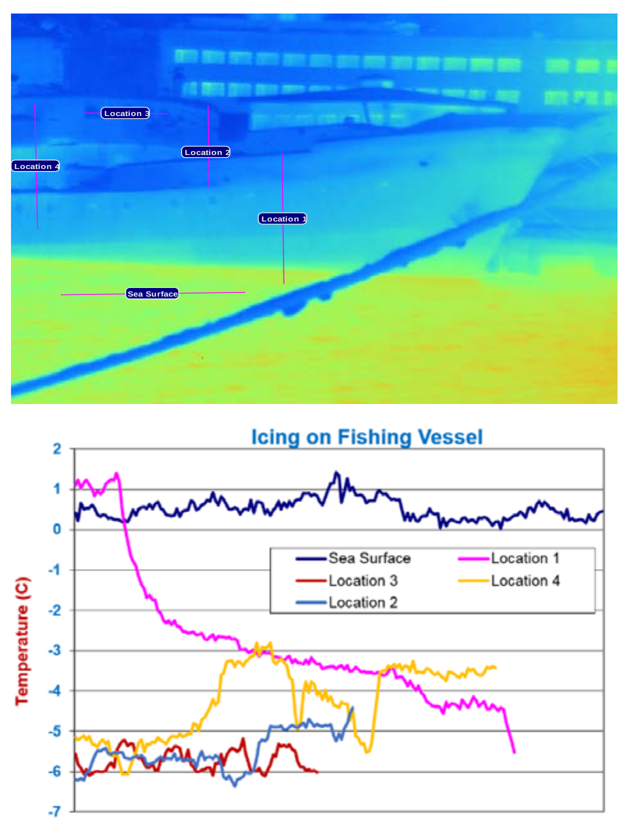


Figure 3. Surface temperature distribution along iced road surface.

Figure 3 shows the results of surface temperature distribution along an iced road surface in northern Norway, where it can be seen that the iced surface areas are marked in blue color and have lowest temperature as compared to un-iced surfaces. Such information about distribution of surface temperature also helps to identify among different types of ice, which eventually can help to improve the road safety. The results shown in Figure 3 represent the case, where ice has already accumulated on the road surface, therefore the iced surface area has the lowest temperature. However, while ice accumulation is in process and super cooled water droplets are hitting the road surface, in that case, latent heat will releases while the droplets freeze and the iced surface area will show the highest temperature. With the help of point based ice detection method, it is not easy to get such detailed information about road surface condition in icing condition.

C. Shipping Vessels

Icing can be a safety hazard for offshore shipping vessels as weight of accreted ice can possibly effect both its safety and stability, therefore actions necessary to improve safety must be considered [1]. Thermal imaging technique of ice detection may be useful for application in marine environment also, especially where incipient icing could cause slipping hazards on deck, stairs and other work areas. Figure 4 shows some results of temperature distribution along different sections of a fishing vessel.



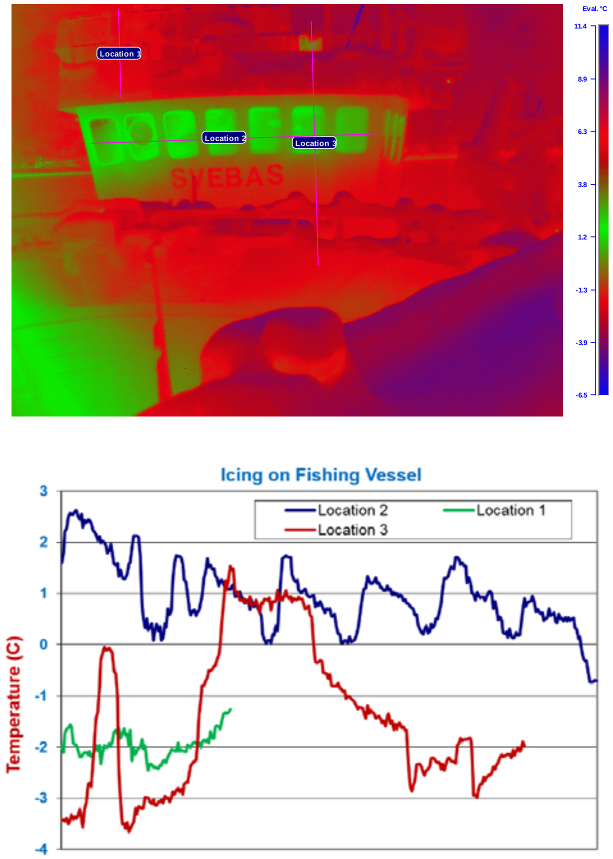


Figure 4. Thermal image of fishing vessels and temperature distribution along selected locations.

It can be seen in Figure 4 that the distribution of temperature is not constant along the selected locations and iced locations have significantly low temperature compared to un-iced surfaces. Such information of temperature distribution is vital to identify the iced surfaces and initiate the de-icing operation accordingly. With the help of passive thermal IR approach, it is possible to monitor the ice accretion along various sections of ships, where ordinary point based icing sensor does not work. A coupled continuous monitoring of significant locations along ships can help to optimize the operation of the anti/deicing systems, which can also help to save the required energy for anti/deicing systems.

D. Communication Towers

Atmospheric icing is a design constraint for the communication towers in cold regions, as these are typically elevated and exposed. Ice buildup on communication towers can cause signal interference, structural fatigue from dynamic loading, guy wire stretch, ice chuck fall and complete tower failure [8]. Due to complex structural integration and installation at remote locations, ice detection and mitigation on communication towers is difficult, but non-intrusive passive thermal IR approach can be a good way to detect the ice on communication tower and initiate the ice mitigation accordingly. Figure 5 shows the thermal IR image of communication tower and respective distribution of ice along the specified locations.

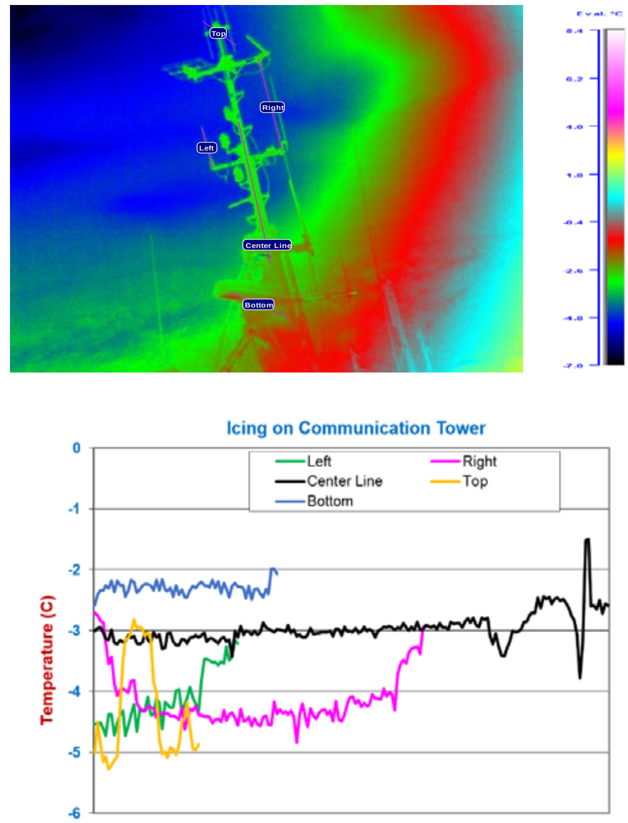


Figure 5. Thermal image of communication antenna and temperature distribution along selected locations.

In this field study, five different locations were selected along a radio communication tower, where based upon thermal radiation and surface emissivity temperature distribution was analyzed to get a perspective about accumulated ice. Results showed different temperature distribution profiles along each location, which indicated that ice is not symmetrically distributed along these locations and maximum ice was observed near the top and right locations of the communication antenna. Such information about distribution of ice along antenna surface can help to optimize the design of communication antenna and design the ice mitigation approach accordingly.

IV. CONCLUSION

This preliminary research work was focused on to use of non-intrusive passive thermal infrared based intelligent sensor technology to analyze the ice distribution along surfaces of different structures in cold regions. Preliminary analysis showed a potential in this technique to better predict the ice distribution along different structures. This technique has an advantage over the available techniques for detection of ice at single point, as with this technique we can successfully predicted the dynamic icing conditions over large surface areas, but it is necessary to further evaluate this methodology by a comprehensive study to build a large dataset from different scenarios before its final implementation.

ACKNOWLEDGEMENT

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REFERENCES

[1]. C. Ryerson, "Ice protection of offshore platforms", Cold Regions Science and Technology, 2011, p. 97-110.

[2]. D. Gregoris, S. Yu and F. Teti, "Multispectral imaging of ice", IEEE CCECE Conference, 2004, Niagara, Ontario, Canada, p. 2051-2056.

[3]. M. S. Virk, "Application of Passive Thermal Infrared Imaging to Study Ice and Snow Accretion on Automobiles in Cold Regions", Advanced Materials Research, 2013, vol. 739: p. 481-485.

[4]. A. Dershowitz and R. J. Hansman, "Experimental investigation of passive infrared ice detection for helicoptr applications", AIAA-91-0667,1991, Massachusetts Institute of Technology, USA: Reno, NV.

[5]. R. Ghani and M. S. Virk, "Experimental Study of Atmospheric Ice Detection on Wind Turbine Blade Using Thermal Infrared Technique", Wind Engineering : The International Journal of Wind Power, 2013, vol. 37, issue. 1, p. 71-78.

[6]. K. Kleissl and C. T. Georgakis, "Bridge ice accretion and de- and anti-icing systems: A review", 7th Internation Cable Supported Bridge Operators Conference, 2010, p. 161-167.

[7]. P. Jonsson, "Intelligent networked sensor for increased road safety", in Department of information technology and media, 2011, Mid Sweden University: Ostersund, Sweden, p. 41.

[8]. N. D. Mulherin, "Atmospheric Icing and Tower Collapse in the United States", 7th International Workshop on Atmospheric Icing of Structures, 1996, Chicoutimi, Quebec, Canada: IWAIS.

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