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Developing a cost effective multi pixel NIR camera for road surface status classification in 2D

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ABSTRACT

One of the major challenges in winter maintenance is automated detection of road surface conditions and especially black-ice. Previous research has shown that it is possible to detect different road conditions by using IR detectors and IR illumination. A major drawback with commercially available solutions is that road status classification is only performed on a single spot on the road surface. Consequently there is a big risk that the single spot is not representative for the rest of the road. A second drawback is the, arguably artificially, high price point of the current commercial systems in relation to the information they offer.
In this research, a multi pixel NIR camera for classification of road status over a 2-dimensional surface has been developed. The goal has been to create a system capable of detecting and distinguishing different road conditions over a surface area.
The resulting product is a patent pending Near Infra Red (NIR) camera able to classify and distinguish between different road conditions in several thousands of pixels on the road surface. Images and data from the camera can for example be used as overlay on a visual image to visualize the current road status to an operator. By utilizing the latest research and best engineering knowledge a patent pending cost effective solution has been constructed at a market price comparable to the existing single point detectors.

Keywords: Camera, NIR, surface status, road condition, classification.

1 INTRODUCTION

There is a great need to have knowledge about road conditions in order to perform correct road maintenance and to initiate warnings for road users. This knowledge is commonly gathered by the use of Road Weather Information Systems (RWIS) [1] and camera surveillance systems (CCTV). In order to assess future road conditions, local climate models and other general forecast models are developed [2]. These forecast models can usually track the situations when severe road conditions may occur, and hence trigger road maintenance tasks such as preventive freezing point depression by spreading anti-icing chemicals. However, there are occasions when the road status situation is not noticed by the prognosis models and RWIS field stations. These occasions often cause severe accidents why it is necessary to improve the ability to detect these slippery road conditions.
Previous research has shown how road images from the CCTV systems together with RWIS data can be used to determine the road condition. The results are promising and they show a high rate of correct classification for some standard road conditions [3, 4]. In order to further improve the possibility to detect different types of road conditions, especially the ability to discriminate between wet and ice, the use of Infra Red (IR) illumination and detectors has evolved. The absorption of IR light by water and ice is well known [5] and it has been found that by examining the absorption in the wavelength band between 1 and 2 µm it is possible to distinguish between a dry, wet, snowy or icy surface [6, 7].
Some commercial sensors utilizes this infrared absorption by water in different phases, for example Vaisala DSC 111 [8], Teconer RCM 411 [9] and Lufft NIRS 31 [10]. These sensors can determine the road condition by observing an approximately 20 cm wide spot in the pavement.

There is however a need to determine the road condition over a road surface section because the road condition can vary between wheel tracks and in-between wheel tracks and from lane to lane. Figure 1 shows a situation where there is ice in the wheel tracks and snow in-between the wheel tracks. It is obvious that a sensor system covering only a 20 cm wide spot will not give descriptive information about the road condition. The requested area coverage for road status determination can be obtained by utilising a NIR camera. Unfortunately NIR camera chips operating in the 1-2 µm wavelength range are very expensive, commonly factors of several thousands more expensive than camera chips working in the visual wavelength range when comparing similar pixel density [11]. This paper describes the development of a cost effective NIR surface status camera that can determine road status covering a road section.

Figure 1. Picture of a road lane section where there are very different road condition in the wheel tracks and in-between the wheel tracks. There is ice in the wheel tracks and packed snow in-between the wheel tracks.

2 MATERIALS AND METHODS

2.1 Theory

The detection method utilises the knowledge about IR absorption by water in the different phases; water as liquid, water as frozen as ice and water frozen as snow. Absorption data for water can be found in literature, see Figure 1. In the research foregoing this product development additional absorption curves were retrieved using a commercial spectrometer unit. It was found that there are some differences between water, ice and snow that should be detectable by looking at the absorption at different wavelengths.

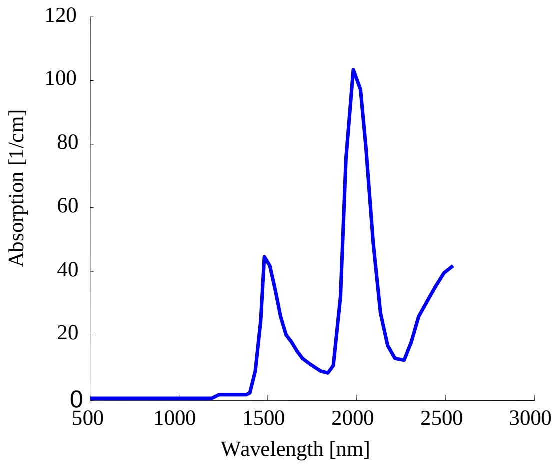

Figure 2. Water absorbtion in the region 500 to 2500 nm [5]. It can be seen that there are some peaks in the absorption that may be used to detect water.

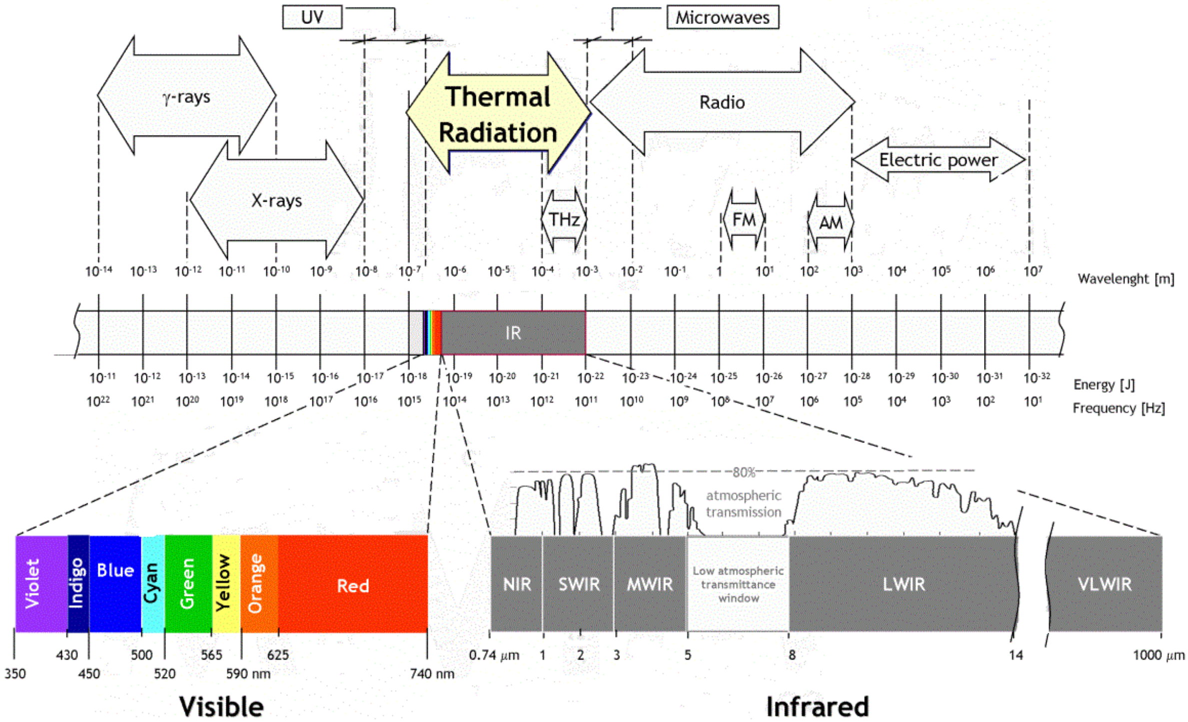

Figure 3. The light spectra and commonly used infrared wavelength bands [12]. The infrared region (0.74 – 1000µm) is marked to the right of the visible region (0.35-0.74 µm). The infrared region is divided into several sub regions, where our interest is focused towards the 1 – 2 µm region. Often the NIR region is considered to span from 0.7 to 7 µm, why we have selected to use the term NIR for the 1-2 µm wavelength band even if it in this detailed picture is named SWIR. It should also be mentioned that the 8-14 µm region is commonly used by infrared thermometers and thermal cameras.

2.2 Hardware construction

As noted above, the cost for a NIR camera chip sensitive in the 1-2 µm wavelength band is usually high. InGaAs is one of the preferred types of detectors in this wavelength band and another type of detector sensitive in the required wavelength band is made of HgCdTe (MCT). Both of these sensor types have a very high Quantum Efficiency (QE) for light in this region [Advances in Infrared Detector Array Technology]. When analysing the cost drivers for the NIR chip development, it was found that the number of pixels is directly related to the price. This means that by reducing the number of pixels the cost of the camera chip can be reduced. By reducing the number of pixels, the resolution of the object being observed by the camera chip will naturally be impaired.

The object to be observed is a road section of approximately 10 x 10 m in size. It is desired to detect differences in wheel tracks and in-between wheel tracks. As seen in Figure 1 significant differences in the road condition can be seen in the wheel tracks and in-between the wheel tracks.

Normally the wheel tracks are approximately 20 cm wide, why the biggest observed area of each pixel should be 20 cm on the pavement. This implies that the minimum amount of pixels should be 50x50 pixels. Such a low resolution image looks more of a checker board than an image, why an overlay of an image taken by a visual camera chip may be useful for interpretation of the image data.

The demand for a minimum size observed on the road surface led to the conclusion that a commercially available NIR chip with just over 50x50 pixels was appropriate for the development of a road area status determination system.

As this low resolution image sensor has a low level video output signal, an image readout circuitry needs to be constructed. Furthermore, this image readout circuitry needs a unit that is capable of handling the correct timing according to the Master Clock Pulse (MCK) used by the camera chip. Only after these electronic designs the image data can be processed by a computer.

For each occasion when the road status condition is to be determined, images taken with the NIR chip covered with different optical wavelength band pass filters are needed. The images are then analysed by a computer model that for each pixel determines if it is aimed at a spot that is dry, wet, snowy or icy.

2.3 Visualisation

The road statuses to be determined are selected to dry, wet, snowy and icy. These road statuses may be colour coded in appropriate manner. For example, the ice should be marked red as it is the most severe road condition. In this research development, the following colour codes were used. dry - green, wet - dark blue, snowy - light blue, icy - red. Each pixel from the NIR camera is then colour coded according to this scheme. In order to make the low resolution classification easy to interpret for road maintenance personnel and operators, the image is preferable overloaded on a standard visual camera image.

3 RESULTS

A NIR image retrieved from the unit can be seen in Figure 4. A visual image taken at the same location and at the same time is shown in Figure 5. The images in Figure 4 are used to classify the road condition to dry, wet, ice or snow. The same NIR images are taken with several different exposure times to ensure that it is possible to find a set of images covering the selected wavelength bands that have appropriate exposure.

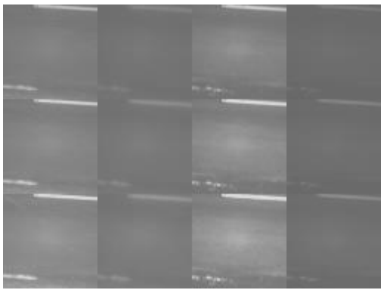

Figure 4. Image retrieved from NIR camera unit. Each row represents images with a specific exposure time. Each coloumn represents a wavelength band.

Figure 5. A visual camera image retrieved at the same time as the NIR image. This image is used as background for the road conditions classified using the images in Figure 4 taken at the same monitoring site.

Some preliminary results from classifications of road conditions can be seen in Figure _ and Figure _.

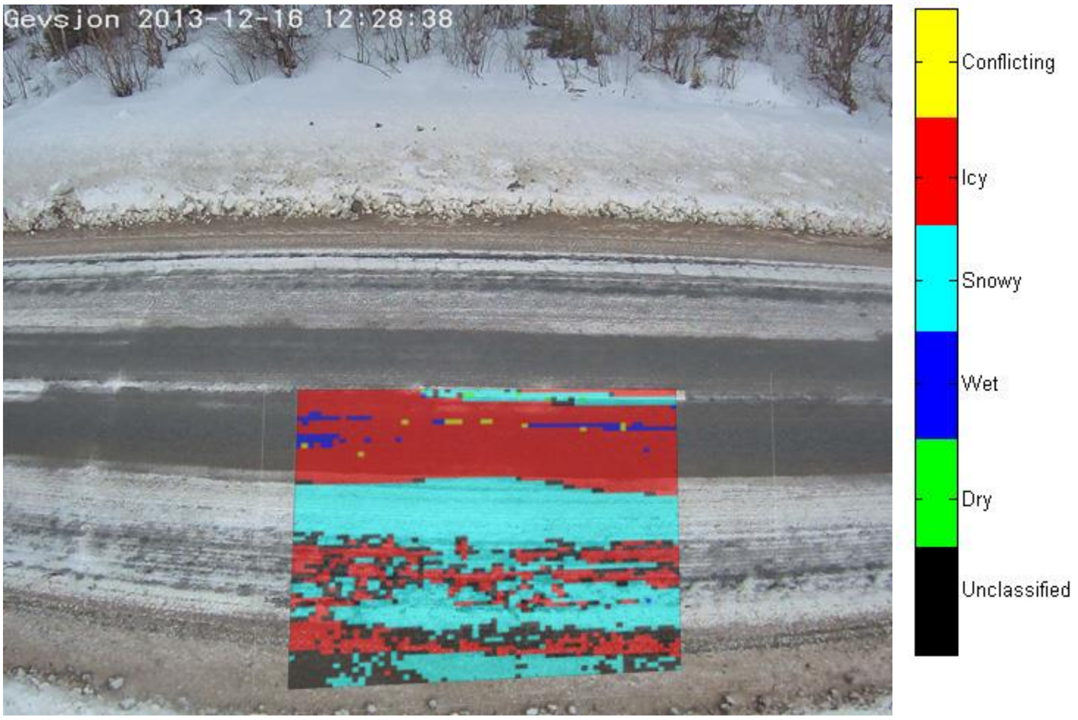

Figure 6. Background image taken with ordinary visual camera system. A classification image made from NIR camera data is overlayed on a part of the visual image. It can be seen that different road conditions are detected on the road surface.

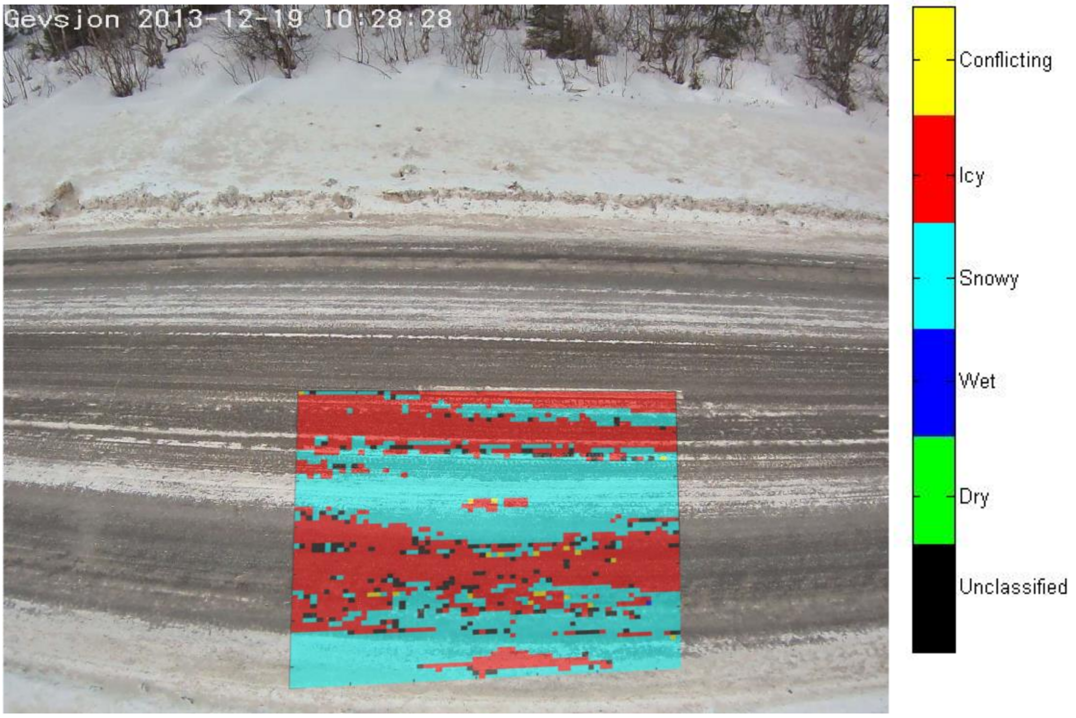

Figure 7. A classification image made from NIR camera data is overlayed on a part of a visual image. It can be seen that different road conditions are detected on the road surface.

4 DISCUSSION

In the existing system, a separate standard CMOS camera unit is used for visualisation of the road condition. This image can be used as an overlay for the road status classified by the NIR camera. In future systems, the visual camera unit may be integrated into the NIR camera housing, thus making the field installation less complex as fever units and cables needs to be installed at the field installation site.
As the NIR camera chip is a cost driven factor in the NIR camera a filter wheel is used for retrieving images of different wavelengths. If the NIR chip were cheaper, another possibility would be to use several NIR chips with permanently attached filters in front of the camera detectors. This construction with several NIR camera detectors would give the benefit of having real time video instead of still images of the road condition. In the case of road side mounted units, the filter wheel solution is good enough because it is enough to be able to update the road condition status on a minute basis. Normally the time period between desired road condition update is 10 minutes to 60 minutes. At the moment there are few indications of drastically lowered prices of InGaAs camera detectors which would imply reconstructing the NIR camera with several camera detectors. Therefore the method of using a rotating filter wheel is the most cost effective solution today and for the near future. The light source used in this system development is a halogen searchlight. A halogen lamp emits light in the wavelength band from visible (0.4µm) to the infrared region (2.5µm) which makes it usable for this NIR camera system. The choice of a halogen lamp is mainly made due to the cost effectiveness of the halogen lighting equipment. Future development of the lighting source will involve IR LED's or lasers that consume much less power and have a longer lifetime than a halogen lamp that is switched on and off regularly.

5 CONCLUSION

Existing road condition determination systems have only determined the road conditions in a single point, which may mean that dangerous conditions have been able to evade detection. An example is the situation with dry wheel tracks with ice in-between the wheel tracks when the surface status detection system is looking at the wheel tracks. The described novel road condition NIR camera is a ground breaking system for determining the road condition over a road section. This means that previous limitations of the area coverage are eliminated and thus the possibility to detect and take actions against severe road conditions that may cause transportation disruptions and accidents.

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