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Toward a Multisensory Expert System for Beach Advisories

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Abstract: This paper presents a case study based on a real world situation to illustrate the use of Earth Observation data and describe the issues that could be addressed using intelligent manufacturing technologies. Components of solutions based on an expert system approach are proposed, and their strengths and limitations are discussed.

Keywords: Environment monitoring, remote sensing, water quality, expert systems, RADARSAT, satellite imagery.

1. INTRODUCTION

Earth observation satellites carry imaging sensors that have a coverage width between tens of kilometers to thousands of kilometers with a trade-off between spatial resolution (the smallest object that be detected) and the width of the image captured (referred to as the swath width). A wider swath typically has a lower spatial resolution than a narrower swath. As the satellite orbits the Earth, it will image along its trajectory which results in a swath of coverage. The design of the orbit enables almost all areas of the Earth to be imaged over a number of days. The cycle is then repeated which allows a specific area on the Earth to be revisited on a regular basis.

The sensors aboard the satellite exploit specific regions of the electromagnetic spectrum. Optical, infrared, thermal infrared, and microwave parts of the spectrum are the most common segments of the EMS exploited. Each object on the Earth has its unique spectral signature and allows it to be distinguished from other objects and is the basis for the design of specific sensors. For example, vegetation has a high response in the infrared and red, but low in the green due to the presence of chlorophyll in the leaves while buildings and soil will have quite different responses because of a lack of chlorophyll-a. Also, healthy vegetation will have a different response than those that are in the process of senescing which allows the two conditions to be differentiated.

These capabilities combined with the repeat coverage of the satellite over the same location allows one to monitor changes in the environment whether it be sea ice extent, crop condition, forest extent, or algae bloom formation in lakes. Although EO sensors can detect change, it cannot definitely identify the cause of the problem. Typically, other sources of information are needed to establish what is happening and for a decision maker to make an informed decision. An expert is often required to analyse the information to determine the current situation. The problem is many organisations do not have the expertise nor the budget to employ a person to fulfill this task. Therefore, it would be a significant advancement if technology could be developed to perform this function.

Cyanobacteria, often referred to as blue-green algae, can pose health hazards to humans with release of toxins into the water. Cyanobacteria can form dense surface blooms when the environmental conditions are favorable. High nutrient loading, warm water temperature, sunlight, and low mixing conditions of the water column combine to enable surface algae blooms to form. Water quality agencies have the responsibility to monitor their levels and respond according to established guidelines. One such organisation is water quality departments responsible for monitoring the water around public beaches. Beach advisories are posted when levels exceed a certain threshold and closed if the levels are excessive.

Water resource personnel take samples at beach sites which are transported by car to a laboratory where the analysis for harmful algae is performed. This is relatively expensive and the turnaround of time of 24 hours is not ideal. Therefore, the sampling frequency is limited with a typical sampling of all beaches once a week and a subset twice to thrice weekly. The problem is algae blooms can disperse as quickly as they can develop. Strong winds tend to mix the algae vertically in the water column and reduce its concentration. If the wind speed drops, the algae can resurface creating a high concentration bloom. Therefore, it is quite possible that a beach which is sampled on a weekly basis may test negatively on those days while a bloom may occur during the gap in time between sampling.

This paper will present a case study based on a real world situation to illustrate the use of EO data and describe the issues that could be addressed using intelligent manufacturing system design and management technologies. The main factors in the design of an expert system for beach advisory are identified and summarized in the paper.

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2. MULTISENSORY MONITORING OF WATER QUALITY

Optical Earth Observation sensors on satellites measure the Sun's energy that is directed to the sensor by atmospheric scattering, reflection from the water surface, in water scattering by suspended matter, and the reflectance from the bottom of the lake.

The Sun's energy or radiation is spread over the electromagnetic spectrum which encompasses a continuum of wavelengths from very short waves (e.g. Ultra-Violet (100-300 nm)) through the visible (the colours that our eyes perceive (400-700 nm), and near infrared (700-5,000 nm) to the thermal region (the heat we feel). Each of the in water constituents have unique scattering, absorption, and transmission properties in the electromagnetic spectrum which yields a specific spectral signature (Cannizzaro and Carder, 2006). For example, chlorophyll-a in phytoplankton absorb blue (430 nm) and red (681 nm) wavelengths, and reflects green which is why it has a green colour (Cracknell et al., 2001; Jensen, 2007). A distinctive peak reflectance is evident in the green band while low in the blue and red sections. In addition to absorption which is used to drive chemical photosynthesis, the light energy can be dissipated as heat or it can be retransmitted as light (chlorophyll fluorescence). The amount of fluorescence and absorption increases with an increase of chlorophyll-a concentration. Two measurable fluorescence wavelengths are at 685 and 705 nm (Gower et al., 2004; Gower, King and Gonclaves, 2008). In contrast, the spectral curve for water with sediment (suspended solids) and low chlorophyll-a concentration do not show the strong absorption in the red band and high reflectance at the fluorescence wavelengths.

Satellite Earth Observation sensors have discrete channels that measure the radiance within selective spectral bands. Channels that are most sensitive to changes in chlorophyll-a concentrations are combined and calibrated to historical in-situ measurements to produce a formula that transforms the radiances into chlorophyll-a concentrations. The Chlorophyll-a products derived from MODIS imagery and described in this paper are calculated from the Fluorescence Line Height (FLH) using an algorithm developed by Lake Winnipeg Basin Initiative Network researcher Greg McCullough (CEOS,of the University of Manitoba). The FLH algorithm which estimate magnitude of chlorophyll fluorescence in reflectance spectra is based on the measurements of reflectance at three wavelengths in the fluorescence spectral zone. In the case of MODIS these three bands are 667, 678 and 748 nm. FLH is calculated using the Surface Reflectance from these MODIS bands. The Surface Reflectance is derived by subtracting additive atmospheric components such as haze from the Top of Atmosphere Reflectance. The product is generated in 1 km pixel size in Lambert Conformal Conic projection and stored in a geotiff format

In addition to optical sensors, microwave sensors can detect algae blooms because the algae dampen the capillary waves on the water surface and show as dark signature (Hochheim, 2010). However, there are issues with false alarms over areas where low wind speeds are observed on leeward sides of elevated terrain. Nonetheless, the ability of a microwave sensor to image through cloud is advantageous since cloud cover can persist for a week or more which negates the possibility to use optical sensors. The benefit of using the satellites in conjunction with the beach sampling program is they can provide daily coverage which will fill in the gaps when samples are not taken.

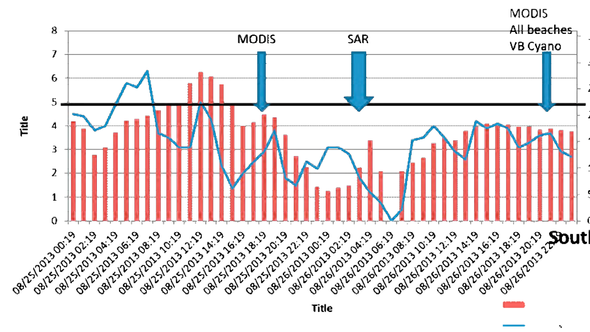

Fig. 1. Wind speed for from 19-27 August.

3. CASE STUDY FOR LAKE WINNIPEG

A case study will be described to illustrate the use of EO data to complement in-situ beach sampling covering the time period from 19 August to 22 September 2013 over Lake Winnipeg, Manitoba. It captures the development and dissipation of algae blooms near the eastern beaches and illustrates:

- the benefits of using both microwave and optical data together to obtain a more complete picture of events,
- issues that can arise in the interpretation of the satellite data, and
- the usefulness of the time series to fill in the information gaps that occur when beach sampling was not performed.

At 0016 UTC on 19 August, a microwave image captured by the RADARSAT-2 satellite shown in 2 was acquired with a wind speed of 1.7 m/s 130 degrees at Victoria Beach (VB). The same wind speed was recorded at the South buoy a wind direction of 168 degrees.

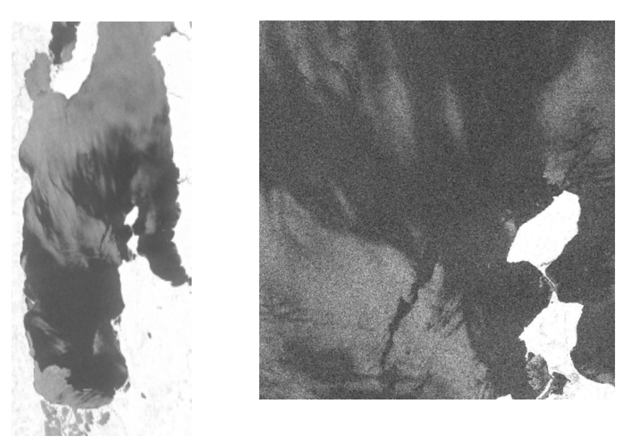

Fig. 2 RADARSAT-2 image acquired 19 August 0016 UTC.