A SURVEY ON OUTDOOR WATER HAZARD DETECTION

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ABSTRACT

Many research to detect the water bodies have been done. But, until quite recently, there still has been very little work on detecting bodies of water that could be navigation hazards. Beside that, the robust water hazards detection is a critical requirement for autonomous off-road navigation and the nature environment is another challenge for this research. The famous mechanism to identify water object can be done by the reflection light analysis or light absorption analysis on water suspect object. For it,. there are some environmental variables to be paid attention, that is : a variable of operation time (day or night), variable reflection at water surface (water in open terrain or water under a shadow from land object) and variable width of water surface (small pond or lake). Other variables include surface wave state, water depth, water turbidity, and presence or absence of scum or other material on the water surface. Among other consequences, these variables affect the ability to measure water depth by optical means and it will influence to the number of variations to be specified for water detection process. This paper focuses on detailed description of the complications involved in water hazard detection along with the state-of-the-art techniques addressing this issue. We try presenting a highlight of the growing interest in the field of autonomous off-road navigation in recent times.

Keyword : Water Detection, Color Imagery, Polarization Imaging

1 INTRODUCTION

One of the most challenging obstacle on the outdoor environments is a water hazard. Water hazards such as puddles and ponds can be identified easily using colour and brightness information under a clear sky when most of the water surface reflects the sky. But, it may be particularly difficult when still water reflects other aspects of the terrain, such as vegetation or buildings.

The failure detection of the water body by automatic vehicle or robotics system will cause fatally for that machine. Sometime it could damage an UGV (Unmanned Ground Vehicle), hence it is preferable to locate water hazard from a distance that is large enough to steer the vehicle away from them. But, unfortunately, the detection of water hazards in an outdoor environment is complicated due to the reasons detailed below.

The important step to detect a water bodies in outdoor environment is recognizing the primary factors influence characteristic the appearance of water. This is can vary greatly, depending on the following factors :

- ambient light (day versus night operation)
- scene elements reflected by the surface (sky, vegetation or buildings)
- width of surface water (a pond versus a lake)
- water depth, Water turbidity and presence or absence of ripples on the surface or shadow

The big challenge here is to formulate a single feature capable of characterizing water under the different scenarios below. In the Figure 1, we can see a scene (left image), that illustrates several appearances of standing water in colour imagery: brighter intensities where the sky is reflected, darker intensities where the water is in shadow, and reflections of ground cover that are close and far away. In addition, no leading edge is visible for portions of the closer water body. It is difficult to create a single detector that locates all these features. So, usually algorithms based on colour image segmentation are not capable of distinguishing between the vegetation and its reflection on water. Another scene (right image) is more complicated because there are changes in illumination along the body of water and are not clearly distinguished from the surrounding terrain.

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(a) (b)

Figure 1. A variety Outdoor scene (a) A Scene when the water reflected a sky and vegetation [5], and (b) A Scene when a water reflected a terrain [6]

A literature review reveals that only a limited number of works on detecting water hazards or on estimating the depth of potential water hazards exist today. Hence, it could be inferred that there is still plenty of scope for research in the field of outdoor water hazard detection.

2 CLASSIFICATION OF OUTDOOR WATER DETECTION METHOD

According research have been done by many researchers, outdoor water detection sensing techniques can be broadly classified into passive and active techniques based on whether they employ a source of radiation or not. For example, vision system based on a colour camera for employing colour image segmentation processing or usage of system base on short-wave infrared camera are examples of passive sensing techniques. Also, we found many researchers use the stereo vision to do image segmentation for this passive sensing technique. On the other hand, the active technique for water detection such as LASER range finders system, also selected by many researchers to improve ability detect the water. This LASER range finders shine a LASER beam and analyse the reflected beam to sense the environment.

A detailed survey of the state-of-the-art techniques concerned with the application of active or passive sensing technologies in outdoor water hazard detection is provided in the subsequent sections.

2.1 Colour imagery based scheme

This is a one of passive sensing techniques. It can be done easily for many off-road conditions. The reflections of sky in water are easily discriminated from the other terrain by their colour and brightness regardless of whether the sky is clear, partly cloudy, or completely overcast and regardless of the surface wave state of water. Colour cameras as a passive sensing devises with the added advantages of being cheap, small and light. Captured colour image segmentation is considered to be versatile in characterising various obstacles including grass, foliage, soil, dry vegetation and rocks.

In the colour imagery based scheme, brightness [I = (R+G+B)/3] and colour saturation [1- min(R,G,B)/I] of the different elements such as the terrain, water and sky are evaluated for manually segmented images taken in outdoor environments. This technique evaluated the average brightness of the sky on two and half times higher than the mean brightness of the terrain. Meanwhile, the average brightness of water where it reflects the sky, is mid-way between that of the sky and the terrain. Thus, the range information obtained from this stereo data could be fused with the terrain type estimated by colour analysis for use in water hazard detection.

Matthies et all [5], developed a colour image classifier based on mixture of Gaussians to exploit the result above (mean and standard deviation of brightness and saturation) to train this classifier on water regions in RGB colour space. Suggest that for still water, the classifier accurately labelled the regions of water reflecting the sky, but misinterpreted the pixel reflecting vegetation as vegetation. Some portion of the sky has been mislabelled as water, though this could be avoided with the knowledge of the horizon. The inherent limitation of the classifier includes the need for performing the training at each new site of operation with sufficient number of images containing correctly labelled water bodies. A way of overcoming this limitation by devising a thresholding criteria. It will explain at section 2.5.

During the day, colour image classification can be used to recognize water by its reflection of the sky; in off-road, open terrain, this is a fairly reliable, easy-to-compute signature. On the other hand, when still water reflects other aspects of the terrain, such as trees, hills, or buildings, it may be particularly difficult. Algorithm based on colour imagery couldn't distinguish water pixels reflecting vegetation from true vegetation.

2.2 Short-Wave Infrared (SWIR) imagery

Another approach to detect a water body is analysing image of it deepness. This can be done with Infrared sensor. In the remote sensing literature, absorption coefficient of pure water in the near infrared wavelengths is higher than that in the visible range and water bodies of any appreciable depth will appear very dark in the near infrared imagery. This fact coupled with the availability of SWIR cameras with wavelength sensitivity from nearly 0.9 to 1.7 µm.

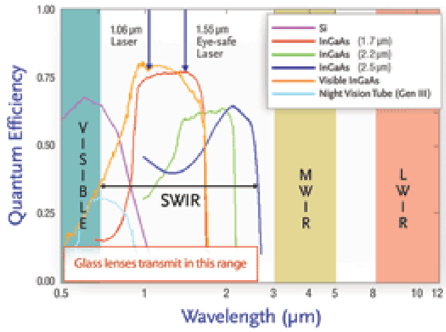

Figure 2. SWIR Wavelength [10]

In the research work presented in [5], found a fact snow and ice have very strong absorption beyond about 1.4 µm, therefore the wavelength region around 1.5 µm to 1.6 µm may be useful for recognizing water, snow and ice. In this research also found a fact ; the water is very dark where it reflects the sky with the angle of incidence at that point is at least 80 degrees. Beyond that, strong reflections of clouds and trees are evident on the water surface. Note that the vegetation all around the reservoir is highly reflective at these wavelengths.

This research implies that SWIR is capable of detecting water at moderate angles of incidence and has the potential to discriminate snow and ice from other terrain materials. But the performance of this technique degrades in regions of water strongly reflecting vegetation or the clouds.

2.3 Thermal Infrared Imagery

Interesting fact of water if we seen from operating time detection (day or night) is the water bodies tend to be cooler than surrounding terrain during the day and warmer at night. Off course, the size of water body will be affected to the temperature distribution and smaller bodies equalize temperature quickly while there is significant contrast for larger bodies of water. Moreover, water has a higher emissivity than other terrain materials and hence, improves the contrast during night.

This fact coupled with the availability of thermal infra red camera ; mid-wave infrared imagery (MWIR) cameras with wavelength sensitivity from nearly 3.5 to 20 µm. Most remote sensing applications make use of the 8 to 13 micrometer range. Water bodies have a thermal region distribution region around 3 to 5 µm and other gases in the atmosphere restricts aerial systems 8 to 15 µm.

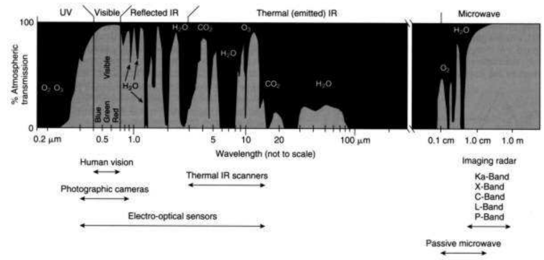

Figure 3. Thermal Infra red wavelengthband [11]

One a important results of the mid-wave infrared imagery (MWIR) based water detection technique employed in [5] show that MWIR certainly offers significant contrast during the period from 12:30 AM to 5:00 AM. However, this technique is limited by the darkening of the water regions near the far shore which is yet to be accounted for.

Analyzing a thermal images of water measures only can be use on the very top layer of the water surface because those wavelengths are attenuated/absorbed very rapidly. In the water content, this is will makes confusing results sometimes, unless you know for certain what covers the area you are looking at or have very precise control of the wavelengths sensed by the instrument (which makes in expensive). Being that and Thermal IR image is digital, using "false colour" really helps interpret them because it can select certain temperature ranges and classify them with a colour while leaving the rest gray. Moreover, most thermal imaging systems have strict technical parameters, for example, detector materials must be kept extremely cold during use (because the emitted radiation being sensed is very weak).

2.4 LASER range Finder based approach

A LADAR system works by firing photons (lasers) at a given object or area, it then measures the time of flight of photons (time to reflect back), this enables a CCD style setup to encode each photon as a pixel and produce a 3D image of the object or area.

The primary advantage of a LADAR ranging system is that the smaller wavelengths of a laser provide high resolution. LADAR can also be used in zero or low light conditions. As well as having the ability to produce images from multiple angles, allowing it to see around obstacles such as trees. Also, the water bodies can return signals for robot mounted LADAR ranging systems owing to the specular reflection at the air water interface. It has been suggested that some of the LADAR energy penetrates the interface and could even produce a range measurement of the bottom of the water body depending on the angle of incidence, LADAR wavelength and the attenuation in the water column.

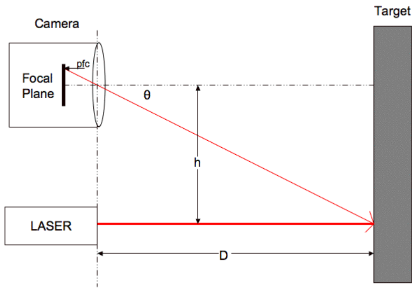

Figure 4. Basic principle of projecting a laser photon onto a target that is in the field of view of a camera [12]

The research from [6] has been modelled the propagation of incident radiation influenced by the above factors. It is enabling us to determine the conditions under which LADAR could be used in detecting water bodies. It has been concluded that within short ranges of shallow water bodies, visible and near infrared LADAR may provide a return value and could be used in detection and depth measurements. In the simulation of [6], within certain range (between 6.5 and 11 metres), scene elements other than water provide return values and the absence of return value could be used to characterise water. Beyond this limit, no return signal is obtained from any object and hence, it is mean not possible to detect water hazards.

The ability of LADAR to detect objects and identify specific features with very high definition of up to 15cm resolution (from a distance of 1,000 meters) will helps in discriminating grass of foliage from other smooth surfaces such as rocks or tree trunks based on local range statistics. But, extreme sunlight can be damaging a laser beam and rounded surfaces (the colors black, blue, and violet) are poor reflectors for this system. So, for the goal of detecting the presence of water body, this system need careful installation, depend on time operation (day or night), and the precision angles of incident laser beam to water bodies object. Another research from [4] has been done to fusion of LASER range finder data with colour information.

2.5 Multi-feature based Water Detection Techniques

A lot of scene of water body in outdoor environment, bring the idea to researchers to combine various techniques to detect the water. In this section, we describe a multi feature based water detection technique.

One of a multi-feature based water detection approach has been reported in [9]. Their technique employs brightness, texture and range reflection features that are fused to detect water hazards. The brightness and texture cues are first extracted by common image segmentation methods such as region growing and clustering. They use an adaptive greyscale threshold segmentation algorithm to acquire the high brightness region. To avoid detection a brightness from sky on the top of image, a seed-expansion algorithm can be used to get rid of the sky regions. First search through top several lines of the image and then find the high brightness points as the seed for 4-neighbour direction expansion. If there is a high brightness neighbour point, this point will be the next seed for expansion. If not, the expansion process stops. After finishing expansion process, the regions which have the high brightness in top of the image will be considered the final possible sky regions which should be discarded away.

Then, the pixels exhibiting larger values for range that are inconsistent with those of their neighbourhoods and also possessing negative height are detected using the 3D information from stereo. In this section, researcher use a normalized cross correlation criteria (NCC) based stereo matching method to find parameter the 3D Information. This information are use to acquire camera coordinate Xc, Yc and Zc, then from that they transform the camera coordinate to world coordinate. After this, they label a region by a clustering learning algorithm ; the region which pixels value are small, that mean it is far away from the location of camera. It is mainly represent the reflection regions which have the characteristic of the sudden distance changes between the surrounding areas.

Finally, the features are fused to detect the water regions in the scene. However, it could be inferred that the performance of this technique highly depends on reliable stereo matching which is highly complicated in water regions due to the absence of texture. Moreover, the performance of this approach in labelling distant water bodies is poor as their range values from stereo have larger errors.

Another method with this Multi-feature based water detection techniques reported by [6]. Rankin has developed a water detection by process three water cues from color, texture and stereo range data stereo. Though, the multi-cue approach allows each detector to target different water characteristics. A certain amount of false detections from each detector is tolerated by applying fusion rules that are, in part, designed to eliminate false detections. Generally, this technique have a better results than any technique based on a single feature. But, to apply this approach we need found many task to formulating a robust fusing scheme capable of accommodating the different factors influencing the appearance of a water body. This is will increase a computational overhead, hence it will complicate their use in real time applications.

2.6 Water detection techniques based on polarization Imaging

This water detection technique based on the physical principle that the light reflected from water surface is partial linearly polarized and the polarization phases of them are more similar than those from the scenes around. Water hazards can be detected by comparison of polarization degree and similarity of the polarization phases. At this technique, there is a two step the water analysis : (1) Extraction of polarization imaging information and (2) Image Processing of polarization image.

2.6.1. Extraction of Polarization Imaging Information

Partial linear polarization can be measured at a pixel level by the transmitted radiance through a polarization filter. The radiance varies sinusoidally with filter orientation. This is based on the work of Wolff et al. [3] and the relevant equations are defined in Equation (1)-(3).

Polarization Phase :

$$Phase\ \theta = 0.5 * \arctan\left(\left(I_0 + I_{90} - 2I_{45} \right) / I_{90} - I_0 \right) \quad (1)$$

$$If\ I_{90} < I_0\ [\ if\ (I_{45} < I_0)\ \theta = \theta + 90\ \ else\ \ \theta = \theta + 90\ ] \quad Intensity\ I = I_0 + I_{45} \quad (2)$$

Partial Polarization or degree of polarization :

$$P = (I_{90} - I_0) / (I_{90} - I_0) \cos 2\theta \quad (3)$$

I_0, I_{45} and I_{90} is a representation of intensity image measurements that are taken at 0, 45 and 90 degrees of polarizer lens. With this, we will determine partial linear polarization or degree of polarization ; the Polarization Imaging Information. The following image is the result of polarizations parameter extraction use Equation (1)-(3) above.

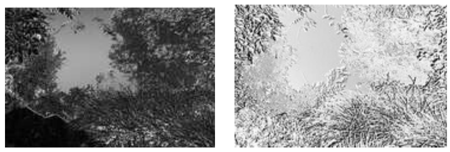

Figure 5. Image results of water hazard detection algorithm : Degree of Polarization (left), Polarization Phase (right) [8]

In Image above, result from polarization degree (left) seen not clear yet differentiate between reflection of vegetation on water surface, but the image result from polarization phase can clearly show a difference of intensity between reflection object with the real object. This is a key for identify the water with polarization method.

2.6.2. Image Processing of polarization image

After calculating the polarization information of the scene, the next step is make a segmentation water region with applying a iterative adaptive threshold segmentation. This algorithm consist of *threshold segmentation algorithm* and *morphology filter algorithm*, The following equation is given by [8]:

$$S = \sum_{i,j} w(i,j) \left| \theta(i,j) - \overline{\theta} \right| \quad (4)$$

when S = Similiar segmentation , θ (i, j) denotes the phase of each pixel in polarization phase images, $\overline{\theta}$ denotes the mean value of certain area in polarization phase image, w(i,j) denotes the weight of point (i,j), commonly choose w(i, j) =1. *Threshold segmentation algorithm* used to mark the region at the image suspected as water. For Polarization phase, all regions with *S* less than the final threshold are possible to be water hazards. But for Polarization degree, all regions with polarization degree greater than the final threshold are possible to be water hazards. *Morphology filters algorithm* are been used to correct discontinuities in segmentation results.

The result of image segmentation by polarization degree (figure 6-a) is not clearly segmented, the algorithm failure to segmented a region that reflected the vegetation. But, for the result of segmentation algorithm by polarization phase (figure 6-b) indicate that entire all water area can be recognized.

(a) (b)

Figure 6. Water segmentation by polarization degree (left) and by Polarization phase(right), water detection is shown in red [8]

3 CLASSIFICATION SCHEME

In this chapter, we propose a scheme for classification of water hazard detection. Classification is not only based on the main water detection technique, but also can be associated with the imaging system, image source, features from environment and image processing focus.

According a survey, we find a lot of method to select the imaging system for detect the water. It can be classified to two imaging system, first using the single camera and using Multiple Camera (stereo system). Then, if we pay attention to image source, there are two important things came out from the status incident light on water detection source light : Intensity light and Polarization light. This classification will depend on a acquisition image camera devices. The difference between camera configuration for capture an intensity light and polarization light can be found at [1],[2] and [3].

Utilization featured from environment also can be used as a source of data processing to detect water. This features consist of ; shadow, depth, temperature and reflected light. At the end of step water detect method, we can classify an image processing step into to three main approach ; image processing based on brightness, saturation and contrast. An Ilustration for basic Image processing approach for segmented a water detection result can be found at [18] and [19].

Detail Relations between classification above with water detection main technique can be seen in the table 1 at the end of this article.

4 CONCLUSION

Water detection technique will help unmanned ground vehicle from damage by traversing through water bodies. Vision sensors and effective algorithm are attractive to be employed for water detection technique because of a number of reasons including their rich sensing, easy availability and cost effectiveness. We believe improvement of detect ability and effective algorithm have a huge potential to be employed for water detection, and gradually more robust methods are being developed.

This paper has then provided a detailed review of the state-of-the-art techniques concerned with outdoor water hazard detection. We have introduced a classification schemes in which we believe any water hazard detection method can fit. The grouping introduced in this paper is a good starting guide for those interested in this research area helping to choose, enhance or even develop a novel water detection technique.

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Table 1. Classification Scheme of method water detection

Imaging System	Single camera	A
	Stereo Camera	B
Image Source	Intensity	C
	Polarization	D
Feature from Environtment	Shadow	E
	Depth	F
	Temperature	G
	Reflected light	H
Image processing focus	Brightness	I
	Saturation	J
	Contrast	K

No.	Water Detection techniques	K	J	I	H	G	F	E	D	C	B	A
1.	Color imagery [5],[6],[15]		X	X	X			X		X		X
2.	SWIR imagery [10],[20],[22]	X			X		X			X		X
3.	Thermal IR Imagery [11],[21]	X			X	X				X		X
4.	Laser Range Finder based [4], [6],[12]	X			X		X			X		X
5.	Multi-feature based [6],[9]	X			X	X	X	X		X	X	X
6.	Polarization Imaging based [8],[13],[14],[16],[17]	X			X				X			X