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Black Ice Detection System Using Kinect

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***Abstract*—An ice detection system is designed using an imaging sensor which has a forward field of a view direction. The proposed system solves the problem of detecting the Black Ice on various surfaces using a depth imaging sensor based on Kinect device. In some places where ice cannot be seen easily from a distance, especially in low visibility, by a human eye, it would be highly dangerous and causes slip. The designed system can detect the forming ice at a distance from 82cm up to 1.52m from the camera. Ice detection system has been tested in five different backgrounds: wood, glass, ceramic, plastic and concrete, and indeed it showed high proficiency.**

Keywords—Black Ice Detection; Vision Algorithms; Depth Sensor Application.

I. INTRODUCTION

During a winter season many surfaces will be covered of snow and ice. Black ice is one important result of this natural process. By definition, black ice is a thin overcoat of glazed ice on specific object surfaces. Black ice has an identical appearance with wet touching in most of the time, and it often forms during calm weather. It is highly transparent and, thus, difficult to see. Black ice usually forms at the late night or early morning on the objects as temperatures continue to drop. Therefore, we developed a prototype system to support detection of black ice to reduce the accidents caused by the black ice.

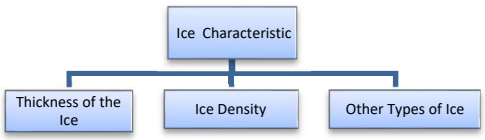

Figure 1: Ice characteristic classification.

II. RELATED WORK: ICE CHARACTERISTICS

Ice and snow are having same environment of formation. However, they may have classified under different physical and mechanical characteristics and properties. Figure 1 shows three major ice characteristic classifications. For example, the solid ice body behaves according to the three stages: elastic stage, plastic stage and brittle stage. These stages are purely mechanic properties. Crystals of the ice fairly belong to the hexagonal system. In fact, the outside crystal shape depends on the condition of the formation.

A. *Thickness of Ice*

The growing of the ice depends only the temperature and the cool air. The heat flow equation shows the relationship between the frozen temperature and ice thickness [1].

$$h^2 = k_0 S \qquad (1)$$

Where h^2 is the ice thickness, k_0 and S represent the ice formation data.

B. *Ice Density*

Black ice has no air entrained in it so its density should be close to this value: 917 k_g/m^3. Density should be calculated to give the geometric information about the crystal. For example, at zero temperature the density has been calculated by [1] and it is 916.6 k_g/m^3. The ice density has a relationship with the thickness. The density on the surface is less than the density in the depth. When the ice density increases, the albedo will decrease [3]. Grain size grow can cause an increase in the density as well [4].

C. *Different types of Ice*

There are many different types of ice. For example, black or/and glaze ice forms when water that's above freezing hits a cold surface that super cools it, as a result, it forms a clear hard, transparent and smooth coating. Pack ice is the result of frozen seawater that freezes at fluctuating temperatures because of the salt content. Glaciers and icebergs are great examples of frozen seawater. Also, Hail is a frozen rain, growing as it falls through the atmosphere.

III. ICE TYPES AND THEIR PROPERTIES

The ice is part of the atmospheric water cycle [5]. ISO-12494 standard defined the ice as any process of building up of ice, while the snow is an accretion on any surface exposed to the atmosphere [6, 7]. Table 1, classifies the ice types:

TABLE 1. The properties of atmospheric icing.

Ice properties				
Type of ice	**Shape**	**Color**	**Tissue**	**Density (Kg/m^3)**
Soft Ice	Eccentric pointing windward	White	Low to medium	200-600
Wet snow	Evenly distributed/ Eccentric	White	Weak (forming), strong (frozen)	300-600
Hard Ice	Eccentric pointing windward	Opaque	Strong	600-900
Black Ice or Glaze	Evenly distributed/ icicles	Transparent	Strong	900

IV. USING KINECT FOR ICE MEASUREMENTS

A flowchart of the proposed vision system using Kinect sensor to detect and measure the ice thickness is shown in figure 2. The main objectives are:

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- The distance Between the Kinect and the Ice with Background Consideration
- Estimation based on 3D View Construction

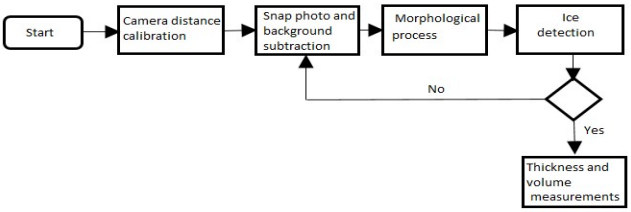


Figure 2: Vision detection approaches using depth camera.

V. KINECT SENSOR CONCEPT

Kinect sensor is a vision device which uses three sensors, making the Kinect as is a 3D camera. Kinect returns two values, distance and player for each pixel. As you can see in figure (3), distance will be measured in mm. The player will be between one to six players [15].

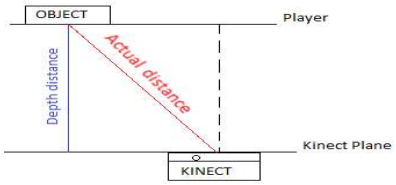


Figure 3. This figure shows that the depth is an estimate of the distance from the object to the camera-laser plane rather than the actual distance from the object to the sensor.

VI. DISTANCE MEASUREMENT

The Kinect has band of 16 bits. the header three bits are used to identify the Kinect players. The rest of thirteen bits present the distance [16]. In fact, any point in the space in the Kinect's field of view has three values X, Y and Z. These values are presented in the horizontal axis, vertical axis and depth axis respectively. The depth Z doesn't present the distance between the point in the space and the Kinect as many people think; however, it is representing the distance between the space point and the Kinect horizon or Kinect plane [13] as a figure (3) shows by line colored in black. Indeed, the actual distance between the point in the space and the Kinect will be calculated as the vector colored in the pink color in the same figure, which mathematically is found by the following formula:

$$D = \sqrt{X^2 + Y^2 + Z^2} \qquad (2)$$

Presenting the distance between the Kinect sensor and the targeted object is done based on the corresponding pixels in between, where each pixel represents the distance of the nearest object in the visible field of that Kinect. Each pixel value represents the distance in millimeters. The maximum depth distance is eight meters, while half of that distance determines the reliability [17]. However, Kinect can determine the distance to any object in field of view by using time of flight (TOF) as other option.

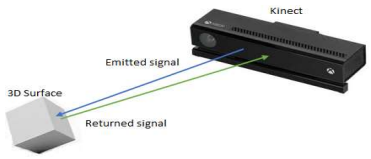


Figure 4. Time of Flight (TOF) of Kinect sensor

This technique was abundantly explained by [18], and the next question used to determine the distance:

$$D = \frac{t_r - t_e}{2}.c \qquad (3)$$

where t_e and t_r represent time for light pulse emitting and receiving respectively, while c is speed of the free light. However, this methodology is hard to be obtained because of dealing with single light. Therefore, the distance can be calculated based on the phase difference of the emitted and the received light.

$$D = \frac{c\,\rho}{2\omega} \qquad (4)$$

$$\rho = \omega(t_r - t_e) \qquad (5)$$

VII. ICE THICKNESS MEASUREMENT

Determining the ice thickness requires knowing many other ice parameters. As in [19] the area of the surface which the ice grows on is important to be known. The density of the ice ρ in kg/m^2. Question (9) is used to measure the ice thickness:

$$th = \frac{m}{\rho.l.w} \qquad (6)$$

Where m is the mass of the ice in the kg. The l, w are the length and width respectively, of designated iced surface. In fact, this question converts the ice mass m in (kg) to the ice thickness th in the (mm) [19]. The ice thickness is changing regarding to the climate change. Therefore, all the measurement should be done frequently as a function of time. The thickness will be measured in specific time regarding to the next function:

$$th(t) = c\sqrt{t} \qquad (7)$$

Here, t presents the time, and c is a constant [20].

VIII. VOLUME OF ICE

Point Cloud Library (PCL) can be used to compute the points cloud for a 3D object and calculate the object volume [21]. However, filtering an image and apply binary mask was used to calculate the object area. After background subtraction, the depth vector will be used to calculate the boxing size. Basically, the boxing distances are presented by the row and vector high pixel values.

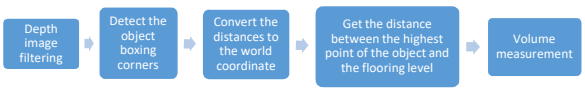


Figure 5. Algorithm to determine ice volume

By applying several mathematical steps, the volume will be determined [22].

$$x = \max(X) \qquad (8)$$

$$V = \max(x) \qquad (9)$$

The pixel summation to present the area presents by x in question (8), while V in question (9) represents the volume measurement. The volume measured based on the area which the ice covers and the height of the ice as in [22]. The height is the depth parameter which presenting the difference height in mm between the background level r_1 and the ice mold's top level r_2 as in question (10).

$$h = r_1 - r_2 \qquad (10)$$

Convert the ice volume to weight is big challenge. The black ice mostly is a solid mass. However, some time it has some gas bubbles inside of it when it formed. For snow the story is completely different, because it has nonsolid objected. Therefore, the weight question will be different. Technically, the weight presents the ice mass which will be used in ice thickness measurement.

IX. IMAGE SEGMENTATION

The Segmentation of the object from the background is made based on the color or the intensity differences. The goal of it, is to identify or/and designate a specific region and represent it in easer way. In this work, the algorithm was used in based on image histogram. Partition the image into different regions based on the similarity is another option and histogram thresholding is one of that techniques [23]. This technique is used as an automatic image thresholding method which divides the image to two weights and balance them in the meeting edge. Figure 6, shows the histogram of the icy object and, indeed, shows the right threshold which can be used to segment that ice from the background.

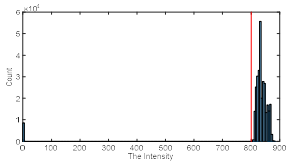


Figure 6. Segmentation based on histogram

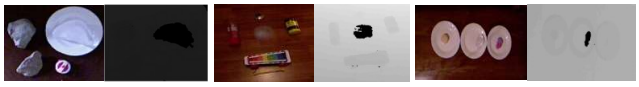
X. EXPERIMENTS AND DISCUSSION

Ice detection system has been tested on five different backgrounds and with different objects. All the images were taken by using Microsoft Kinect I in a controlled environment. The figures 7, 8, 9, show some of these examples. More explanation will be provided in a later section. RGB and depth view they came side by side to show the environment of the work. Each test was repeated many times to insure the system robustness. In all cases the system could detect the ice regardless to the used background and the place illumination.

Glass B.G Plastic B.G Wooden B.G

Figure 7. a: Ice mold in RGB view, b: Depth view to same Ice mold. Different backgrounds (B.G) were used and the system gaves same result in the detection perspective.

The system passed different tested to ensure that the system used the same principles to achieve same efficiency.



abc

Figure 8. a. RGB & depth images of hot and cool rocks with plastic object mixed with ice on ceramic plate
b. Mixed of objects with ice mold on same background.
c. Detection test by mixing Icy milk, Ice mold and Ice cream

Figure 9. Ice mold on plastic background in dark place. a: Here the gray image was converted to RGB image to make more visible. b: the BW for same image after applying morphological process on the image

Instead of working on depth image, we applied a gradient technique to the image and then applying the sobel algorithm to show the edges of the targeted object. And then apply the watershed algorithm. This step to approve closed edges, in other words, full object view. Regarding to physical theory: Kinect sends the IR signal which will be flooded by natural radiation over the surface of the ice. However, in the positive environments, the ice will reflect a high value of the IR beams and absorb or scatter the rest of that radiation beam [24]. Because of that absorptivity/emissivity is very high in the IR reference, the ice will appear black [25]. The ice color can be taken in terms of single scattering or multi scattering. The highest solar radiation will be captivated near by the surface of the ice and that is due almost totally to the near IR radiation. On the other hand, all the other visible lights will recombine after few scatterings [3].

A. IMAGE SEGMENTATION

The RGB Segmentation of the object from the background is made based on the histogram. The figure (6) shows the location of the used threshold. Because of the ice mold is per sized, so the threshold is estimated manually. Otherwise, automatic thresholding will be applied.

B. DISTANCE MEASUREMENTS

The distance between the Kinect and the player and/or the top laver of the object (ice mold) is presented by a vector which can be measured by the question (2).

In this work, by using point cloud map (PLC), we determined the distance between the Kinect and the background level, which is in this case the floor level, by 1.23m. The error rate was around 2cm.

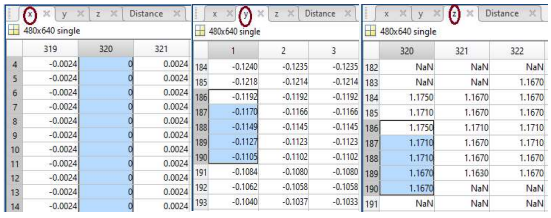
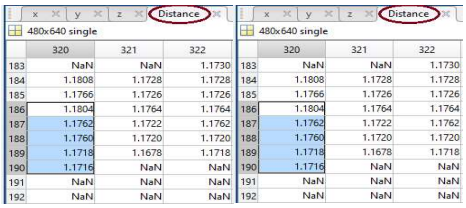


Figure 10. The localization matrixes of the ice mold calculating from the all the 3D values matrixes of X, Y and Z

C. Ice Thickness Measurement

By using question (10), the ice thickness can be defined in this case by $h = 1.2398 - 1.1716 = 0.0682m$. comparing that with the physical measurement which 0.04m, i.e. with error of 0.02m.



480x640 single

	320	321	322
183	NaN	NaN	1.1730
184	1.1808	1.1728	1.1728
185	1.1766	1.1726	1.1726
186	1.1804	1.1764	1.1764
187	1.1762	1.1722	1.1762
188	1.1760	1.1720	1.1720
189	1.1718	1.1678	1.1718
190	1.1716	NaN	NaN
191	NaN	NaN	NaN
192	NaN	NaN	NaN

480x640 single

	320	321	322
183	NaN	NaN	1.1730
184	1.1808	1.1728	1.1728
185	1.1766	1.1726	1.1726
186	1.1804	1.1764	1.1764
187	1.1762	1.1722	1.1762
188	1.1760	1.1720	1.1720
189	1.1718	1.1678	1.1718
190	1.1716	NaN	NaN
191	NaN	NaN	NaN
192	NaN	NaN	NaN

Figure 11. The distance matrixes of the ice and the background to find the ice mold thickness

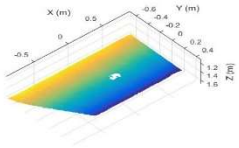


Figure 12. Point cloud map shows the location of the ice mold in the three dimensions

D. Volume Measurement

Point Cloud Library (PCL) was used to compute the points cloud map of the object and then this data is used to calculate the object volume [21]. The results are presented in table (2) for four ice mold samples.

TABLE 2. Shows the volume measurement based on the other measurements.

Sample No.	Weight (gm)	Blobs Area (Sq. pixels)	Thickness (cm)	Volume (m^3)
1	360	12200	4	0.0004
2	224	10961	3	0.00025
3	102	7493	1.2	0.000113
4	33	6187	1	0.00037

XI. Conclusion and Future Work

In this paper, we proposed Fully-Black Ice detection system based on hybrid Kinect refinement vision algorithm that achieves high accuracy, depth view and detection of any kind of challenging surfaces in a scene. The measurements were done based on 3D view which was generated by PCL data. Ice thickness and volume shows very low error rate. For distance and thickness the error was not more than 2cm. Ice mass still done manually. For future work, all measurements: mass, thickness and volume will be calculated automatically out of the Ice PCL data.

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