Integrating Computer Vision Technique to Support Tsunami Early Warning System

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***Abstract*—Tsunami Early Warning System (TEWS) is built for minimizing impact of tsunami disaster. The generic system consists of two components: the first is sensor network for tsunami detection and the second is interconnected communication infrastructure for evacuation notification. In this paper, additional sensor based on computer vision technology is proposed for observing ocean and wave condition. This technology, combined with other sensors technology, will increase the effectiveness of the TEWS. In more detail, image frames captured from surveillance video camera are analyzed and interpreted semantically using imaging analysis techniques. If the system considered a tsunami-like situation based on image, it will transmit a warning signal to a centrally integrated system. The developed application adopted DeWa, a multiaspect framework for object detection that has been previously implemented. Although this camera-based TEWS has not been implemented in realistic situation, it has been successfully tested using extracted image from a tsunami-like wave video.**

I. Introduction

Computer vision is an interesting topic as well challenging, not only for researchers in the field of computer science but also for researchers in the other fields of science. Various visual activities that are easily conducted by humans, in fact is not simple if it is done by machine [1]. Studies that explore computer vision methods and technologies for analysis and interpretation of semantic meaning of digital image have been widely performed, however research on visual observations of the tsunami based on imaging analysis is rarely found in the literature. Similarly, research related to TEWS, especially in the detection, still focuses on non-visual equipments such as seismograph and buoy.

In this paper image-based visual observation using another sensor, in this case a camera, has been proposed. The description including computer vision methods and technology to support and improve accuracy, efficiency and reliability of the Tsuname Early Warning System so that the impact of disasters nature can be minimized. Experiment has been carried out with limited to the simulation using the existing digital imagery stream. Nevertheless, the simulation results show the promising result of the methods that have been developed to detect changes ocean conditions based on specified parameters.

II. Problem Description

A. Tsunami Early Warning System

Tsunami early warning system has been widely developed to accompany the tsunami disaster [4][5]. The researchers in the country that experiencing this natural disaster also have conducted relevant research [6][7]. Furthermore, the geophysycs, climatology and meteorology council of Indonesia (BMKG) had already adopted the TEWS, installed in areas that are presumably to be the impact of the tsunami disaster [8].

Theoretically a tsunami early warning system consists of two parts [9] which is (i) the detection part, for determining the emergence of a tsunami (have to know a tsunami has occurred), and (ii) evacuation notification, for conveying the warning of the tsunami (have to say a tsunami has occurred). Literature reports that several devices or sensors are used to detect tsunami such seismographs, buoy, tide gauge, satellite receiver, GPS stations, and integrated data processing site.

Based on the literature, the research related to the use of visual observation technologies such as camera sensors for tsunami early warning has not been widely reported in scientific publications. However, research that monitored the height of the water (camera-based water level measurement) can be found in the literature [10] and became the basis of the research outlined in this paper.

B. Tsunami Model

The illustration in Figure 1 shows a subduction earthquake (one where a denser plates shifts below its neighboring plate, at left). Energy is transferred and the displaced water forms a wave. The steps of tsunami occurence can be categorized into three phases, (i) Generation (ii) Propagation and (iii) Run-up/down and modelled in Figure 2. Speed of propagation of

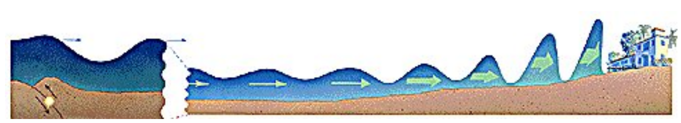

Fig. 1. Illustration of Tsunami

the tsunami depends on water depth. For the shallow water, speed of tsunami is approximated as

$$v \approx \sqrt{g \cdot h} \tag{1}$$

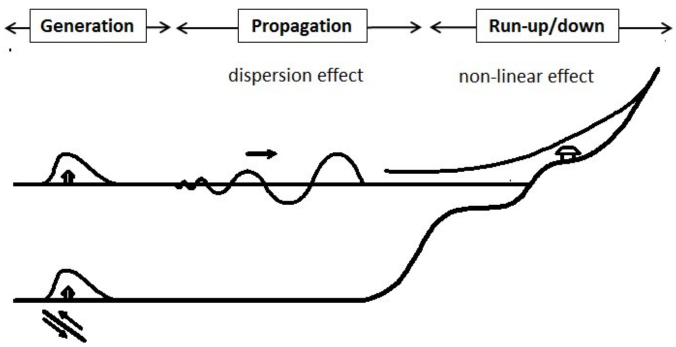

Fig. 2. Tsunami Model

where h is the water depth in meters, g is the earth's gravitational force ($9.8m/s^2$). At a depth of 4000 meters tsunami propagates with a speed of 700 kilometers per hour. At a depth of 10 meters, the velocity drops to 36 kilometers per hour. As the tsunami approaches shore, the depth h of course decreases, causing the tsunami to slow down, at a rate proportional to the square root of the depth, as above equation. Unfortunately, wave shoaling then forces the amplitude (height) A to increase at an inverse rate as follows

$$A \propto \frac{1}{\sqrt{h}} \tag{2}$$

If the water depth is 400 meter and then decreases to 4 meter, then we have a 1/20 Amplitude rising to a 1/2 Amplitude, which means the wave will suddenly become 10 times higher. So a 1 meter high wave one kilometer from the shoreline, suddenly becomes 10 meters high as it gets to the shoreline.

III. Proposed Method

A. Wave Observation Modelling

Physically, the theoretical system of visual wave observations is developed by installing high-quality static cameras at specific location on the shoreline that monitor the movement of waves and ocean conditions continuously (see Figure 3). This

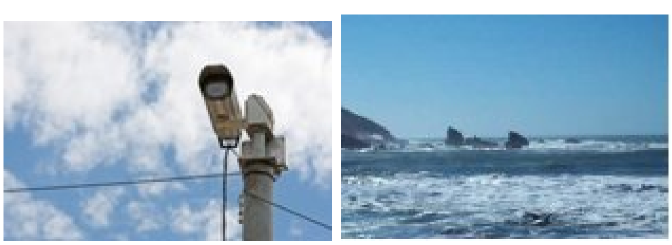

Fig. 3. High Performance Camera Ocean Monitoring

nonstop surveillance system is integrated with existing TEWS. Streaming images from the cameras intelligently processed with special computer vision techniques. Other location that can be used to put camera is at the buoy. Based on NOAA DART platform, in a buoy there are many parts related to communication that make a camera placement is possible.

Streaming data from installed video cameras will be transmitted to centralized high performance computer connected as TEWS data processing clusters; image frame of each streaming will be processed through several stages of digital image processing techniques and then analyzed using computre vision algorithm to generate semantics value (meaning) that provide ocean conditions information in realtime and 24-hour surveilance machine-based fashion. One technique used is the water level detection technique, when water levels above the maximum limit, then the system will generate early warning signals which will be analyzed automatically whether this indicates hazardous conditions or not.

The use of this monitoring system will improve the performance of early warning system due to surveillance processes are performed continuously by machine. The visual observation will help government and people to proper action that should be done. The limitation of this system is that there is a limited (very short) time between detected tsunami condition and action for evacuation. Also it is inevitable if false alarm condition happens caused by machines failed operation or other natural disturbance.

B. Wave Image Interpretation Method

Block diagram of the designed system to obtain the meaning of the waves image is presented in Figure 4. This method is developed based on previous research [13].

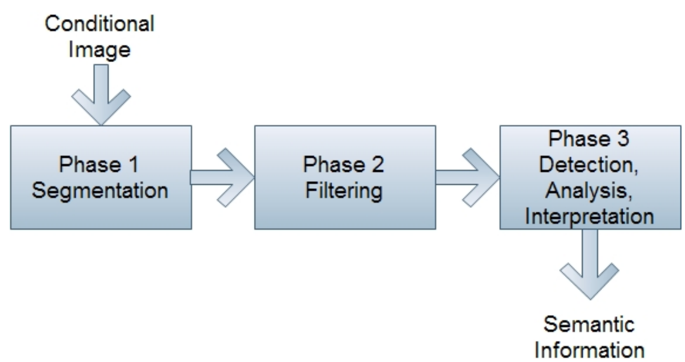

Fig. 4. Processing Phases

Conditional image is realtime extracted image obtained from video camera consist of ocean condition. This image is segmented to obtain light and simple image without sacrifying information detail which is important for the next phase. Filtering phase is important to clean the image so the wave feature is localized and ready to analyze and interpreted in phase 3. The analysis and interpretation method utilizes the human-like interpretation based on common rule of visual observation. Due to dynamic possibilities of wave appearance, the process is reduced and simplified into fundamental form of tsunami-like wave.

In the segmentation stage, the image will be processed with the following formulation.

$$\sigma_w^2(t) = \omega_1(t)\sigma_1^2(t) + \omega_2(t)\sigma_2^2(t) \tag{3}$$

where ω_1 and ω_2 are the probability of two classes that are separated by a threshold t, while the σ_w^2 is the variance of the classes.

From the above formula is shown that the minimization of the variance will be the same class with class variance maximization, as shown below.

$$\sigma_b^2(t) = \sigma^2 - \sigma_w^2(t) = \omega_1(t)\omega_2(t)(\mu_1(t) - \mu_2(t))^2 \qquad (4)$$

The algorithm is as follows:

1) Calculate the histogram and the probability of each level of intensity
2) Set initial value of $\omega_1(0)$ and $\mu_1(0)$
3) Perform the following steps for all possible threshold $t = 1 \ldots maxints$
   a) Update ω_i And μ_i
   b) Calculate $\sigma_b^2(t)$
4) Optimal threshold is obtained from the maximum value of $\sigma_b^2(t)$.

In the filtering stage, objects that are not part of region of interest (ROI) are cleaned. Filtering process is done as follows:

If $f[x]$ is a binary image with value 1 for the object and the value 0 for the background, then the transformation of the image of a moving window $W = \{y_1, y_2, y_3, \ldots, y_n\}$ of the image can be written as the following:

$$\psi_b f[x] = b(f[x - y_1], \ldots, f[x - y_n]) \qquad (5)$$

where $b(v_1, \ldots, v_n)$ is a boolean function of n variables. Mapping $f \mapsto \psi_b(f)$ is called a boolean filter. By choosing various value of b, it will get the desired transformation of the image. For example, if b is the AND operator, then the result of shrinkage (shrink) from the image. Conversely, if b is the OR, there will be expansion (expand) the image.

The last phase is to analyze the object to obtain the meaning of the image. It is assumed that the waves propagate toward the coast (mainland) in a pattern resembling a sine function. If the wave's characteristics is confirmed as tsunami waves, the waves will be getting higher and higher (amplitude increase). Due to the use of two dimensional space then the wave display on screen the closer will be even wider and greater. Figure 5 illustrates the image of the wave at time t.

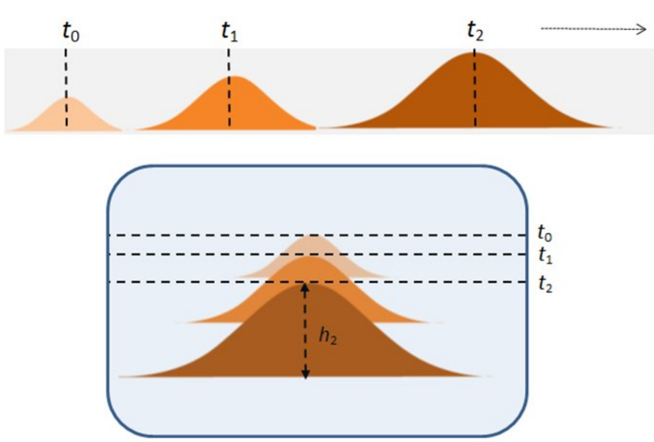

Fig. 5. Wave Propagation Displayed in Monitor

Formulation of wave height in the context of two dimensions assumed by the following formula:

$$H = \sum_{i=0}^{n} \uplus h_i \qquad \forall t_0 \ldots t_m \qquad (6)$$

$$if\, H > T\, then\, D \qquad (7)$$

where H is the accumulation of waves height h_i, T is the safety threshold value and D is a warning signal.

Illustration of the overall process can be seen in Figure 6. Image 6(a) is the original image from the camera, the image of 6(b) is preprocessing result and image 6(c) is the result of processing in which the position of the waves are marked as such and measured according to the desired characteristics.

Fig. 6. Wave Digital Image Detection Process

IV. Experimental Result

The current data used for experiment is not fully reflect the real situation. Some problems are (i) experiments are still using the image data (ii) the video data that is used just as it is, not deliberately taken from the field (iii) partial image data is not taken at the frontal position (iv) the camera used did not have the expected criteria.

The data used is extracted from the video 'ocean waves' as many as 150 frames. Figure 7 displayed experimental result for 10 frames data from t_0 to t_10 as follows (left-right).

Wave is marked with lines above (yellow line) and below (red line). The distance of these two lines indicates the width or height of the wave that can be measured if camera is placed properly. The line position is dynamically change according to wave movement. The numerical value of line position is obtained by image scanning and processing with wave features as basis for wave image analysis. The numerical values that are detected then normalized to be able to display on the monitor.

Table I shows some result numerical result of this method. *Frame* is the image sequence number, *Top* is the line position of the first detected wave from above, *Bottom* is the end of the wave, estimated based on the widest wave. *Diff* is the difference between *Bottom* and *Top*. *nTop* and *nBottom* are normalized value of the line position that containts wave image. Figure 8 shows the visualization of analysis of the wave size (width or height) with an interval of video extraction by 1 frame per second. It can be concluded that there are large waves in the first seconds, then for about 100 seconds the movement of the waves is quite small and at the end of time there are several hikes that show the movement of the waves when enlargement occurs sporadically.

Other analysis is shown on Figure 9 using radar visualization to display the distribution of wave motion detection

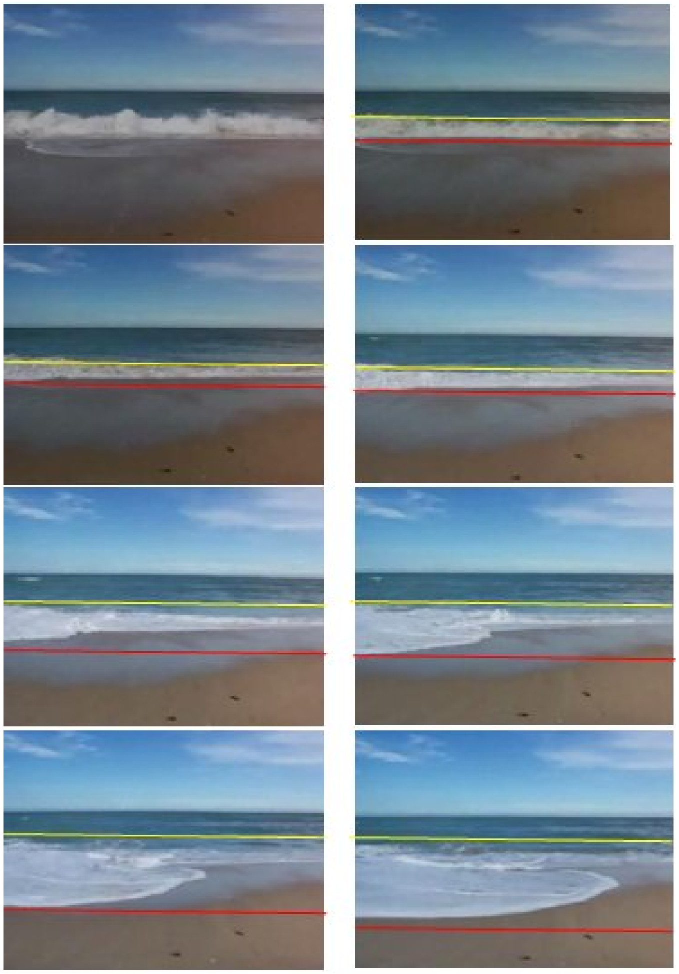

Fig. 7. Some Result From Wave Experimental Data

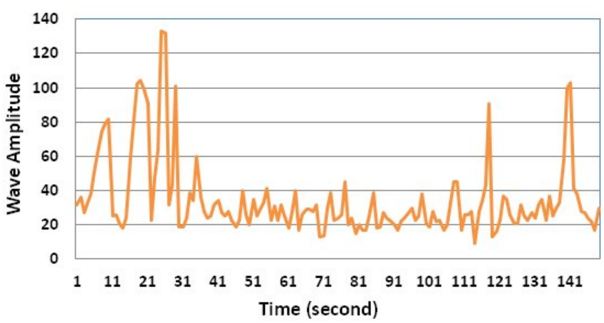

Fig. 8. Graphical Analysis of Wave Experimental Data

results. The data are normalized to facilitate the required distribution. Each end shows the value of *nTop* and *nBottom* that are graphed relative to the center. It means that the longer end the higher wave movement. From this chart it can be concluded that There are only several extreme wave movements so the ocean is wavy but not in extreme fashion.

The results of the work were not compared with a ‘gold standard’. As mentioned before, the data frames used for the experiment were extracted from a tsunami video. To get more accurate result of the method, in the future, a real situation experiment could be performed in a place where tsunami can occurs.

TABLE I
SOME NUMERICAL RESULT OF WAVE DETECTION

Frame	*Top*	*Bottom*	*Diff*	*nTop*	*nBottom*
2	105	137	32	0.875	0.578059072
3	103	139	36	0.858333333	0.58649789
4	108	135	27	0.9	0.569620253
5	119	152	33	0.991666667	0.641350211
6	116	154	38	0.966666667	0.64978903
7	120	171	51	1	0.721518987
8	110	175	65	0.916666667	0.738396624
9	114	189	75	0.95	0.797468354
10	110	189	79	0.916666667	0.797468354
11	104	186	82	0.866666667	0.784810127
12	98	123	25	0.816666667	0.518987342
13	103	129	26	0.858333333	0.544303797
14	108	129	21	0.9	0.544303797
15	116	134	18	0.966666667	0.565400844
16	110	134	24	0.916666667	0.565400844
17	114	173	59	0.95	0.729957806
18	110	191	81	0.916666667	0.805907173
19	107	209	102	0.891666667	0.88185654
20	94	198	104	0.783333333	0.835443038

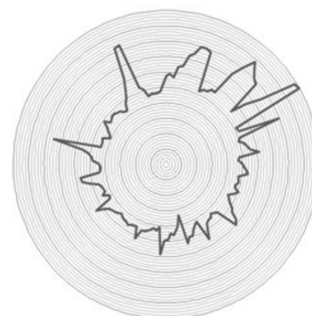

Fig. 9. Wave Distribution in ’ocean waves’ Video

V. CONCLUSION AND FUTURE WORKS

1) In this paper we presented a method for improving the performance of tsunami early warning systems using sensor camera.
2) From the experimental results using static images showed that the method used is able to work well, although still found deficiencies and inaccuracies.
3) Testing methods are still in early stages of the simulation in laboratory. It has not been tested in real conditions.
4) Use of multi-aspect method to perform the phases in the processing of data need to be continually developed to improve the accuracy of detection.
5) The use of advance geometry such as stereo vision might increase the accuracy of the detection.
6) The equipment especially high performance camera that will be used in realistic situation need to be considered carefully so they will solve simple detection problem such as lightning and focussing.

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