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An Enhanced SAR-Based Tsunami Detection System

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***Abstract*—**Tsunami early detection and warning systems have proved to be of ultimate importance, especially after the destructive tsunami that hit Japan in March 2012. Such systems are crucial to inform the authorities of any risk of a tsunami and of the degree of its danger in order to make the right decision and notify the public of the actions they need to take to save their lives. The purpose of this research is to enhance existing tsunami detection and warning systems. We first propose an automated and miniaturized model of an early tsunami detection and warning system. The model for the operation of a tsunami warning system is simulated using the data acquisition toolbox of Matlab and measurements acquired from specified internet pages due to the lack of the required real-life sensors, both seismic and hydrologic, and building a graphical user interface for the system. In the second phase of this work, we implement various satellite image filtering schemes to enhance the acquired synthetic aperture radar images of the tsunami affected region that are masked by speckle noise. This enables us to conduct a post-tsunami damage extent study and calculate the percentage damage. We conclude by proposing improvements to the existing telecommunication infrastructure of existing warning tsunami systems using a migration to IP-based networks and fiber optics links.

***Keywords*—**Detection, GIS, GSN, GTS, GPS, speckle noise, synthetic aperture radar, tsunami, wiener filter.

I. Introduction

TSUNAMIS are classified as a major natural hazard that has the ability to cause great damages and loss of life within minutes on shores near their source. Tsunami can occur at any place there is a large body of water, even large lakes. From observations of scientists and historical sources, Tsunamis can occur in all larger seas of the world, and 85% of tsunamis happen in the Pacific region causing destruction within hours across an entire ocean basin. Thus, fatal tsunamis occur in geologically less active oceans such as the Atlantic, the Indian Ocean or the Mediterranean as well.

Since tsunami are mostly caused by seismic activity of tectonic plates, they are often found in the most active fields of the earth around the Pacific Rim, a region of high tectonic activity in the Pacific Ocean along the "Pacific Ring of Fire". In the Pacific, there were 17 tsunamis from 1992 to 1996, and they took nearly 1,700 lives.

The consequences of tsunami can be devastating especially after witnessing the 2011 Japanese tsunami. Tsunami waves have the power to knock down buildings, crush and flip vehicles, lift giant rocks and demolish houses. Furthermore, Tsunami can cause millions or even billions of dollars worth of damage. They can produce an economic decline in order for the affected country or countries to rebuild and recover from the caused damages.

Once a tsunami is set in motion, there is no way to stop it but there are several ways to avoid losses of life. In fact, the Japanese government has invested billions in coastal defenses against tsunamis by building concrete sea walls to reduce the impact of the waves and gates that slam shut to protect harbors. But for large tsunamis, these methods won't be effective. New ways must be established to make sure people know when a tsunami is coming and where they can run to get out of harm's way.

In this research, we study the tsunamis caused by earthquakes; an earthquake has a high probability of occurrence which requires the need of enforcement of comprehensive anti-tsunami measures in the affected region. Consequently, a system must be employed to accurately collect tsunami information, determine recovery actions and distribute this information to the local residents. These real-time forecasting and alert systems will prevent loss of life and reduce the damages. An effective end-to-end tsunami early warning system can accomplish these tasks and save thousands of lives from the devastating tsunami [1]-[5].

The system starts with the monitoring of seismic events and determining the earthquake magnitude and epicenter, then it detects tsunami waves. To confirm earliest arrivals, amplitude of waves and arrival time of tsunami, the system requires a prior knowledge of modeled tsunami propagation. The system ends with a well prepared community that is capable of responding appropriately to a warning. Indeed, newspaper reports about undersea earthquakes and movies about meteor-inflicted tsunamis have contributed to public awareness of the threat. Also for example, subscribers to the system will reliably receive a warning to their mobile telephones, as and when a dangerous tsunami is evoked.

The key components of an end-to-end tsunami system are to provide real-time monitoring, alert of seismic and tsunami activities, timely decision making, and dissemination of tsunami warnings, advisories and information.

II. General Tsunami Warning System

There is no possible way to stop a tsunami once it's generated, but that doesn't mean that lives can't be saved, and losses can't avoided in case a tsunami strikes. Tsunami detection and warning system is the answer. Such a system detects the propagation of a tsunami before it strikes the shores and therefore gives the public to take the appropriate actions and save their lives and belongings.

The concept of such a system is to detect any usual seismic activity under water, then automatically and as fast as possible

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judge whether the earthquake could generate an earthquake. After this process, bulletins must be issued by the center to inform those in question about the earthquake and the risk of a tsunami. If judged necessary, the water level is monitored and is compared to a pre-calculated threshold, then the bulletins are updated and the finals ones are issued. National Tsunami Warning Centers (NTWC) and Regional Tsunami Watch Providers (RTWP) are responsible for the collection of data and information from locally maintained and international earth data observation networks.

A comprehensive tsunami detection and warning system [6]-[10] consists of: (1) Seismic data, maritime sea level data monitoring and collection, including satellite altimetry to measure seal level height and a hybrid GPS-GIS to measure the size of earthquakes; (2) An integrated secured communication network of surface-based and satellite-based telecommunication links of point-to-point circuits and multi-point circuits, termed GTS, to connect meteorological and other centers throughout the world; (3) An observing system, which is effectively a virtual seismic network, termed Global Seismic Network (GSN), to measure and record all seismic vibrations, thus providing earthquake locations, hazard mitigation and emergency response; (4) Regional satellite-based dissemination and notification systems using an efficient budget link analysis; (5) Additional dissemination and notification systems using SMS to mobile phones, automated earthquake and tsunami web pages, facsimile to disaster agencies, broadcasting systems (radio, TV), sirens and alarms systems etc ...

III. Proposed Detection and Warning Systems

A. Early Warning System

Due to the lack of appropriate sensors, the system was simulated using test signals. Instead of seismic sensor, Matlab Data Acquisition Toolbox with a sound card built into the laptop was used. Microphone and speakers are the data acquisition and output devices.

The first part in this system simulation is to obtain the seismic data from stations to monitor the occurrence of an earthquake. The program initiates once it's asked to obtain seismic observations. In this case, the seismic event occurs when the sensor detects a sound higher than a specified threshold. Otherwise, there is no earthquake event. For instance, when the sound is not loud enough, no earthquake is detected. In the case where the sound exceeds threshold, i.e. an earthquake occurs:

1. The epicenter of the earthquake is located using the GPS triangulation method
2. Earth data observations are required to study the effect of this seaquake.

In this work, because of the lack of the needed seismic sensors, the real-time seismic data were obtained from a reliable authorized website [11]. Once these data are available, an initial bulletin is issued and sent by email to the emergency authorities based on the magnitude of the earthquake and its depth. The content of the bulletin (i.e. decision about the risk of a tsunami generation) is automatically based on Table I.

TABLE I
Bulletin Content Based On the Decision about a Tsunami Generation Risk

Earth-quake Depth	Earth-quake Location	Mwp	Tsunami potential	Bulletin
< 100 km	Under or very near the sea	≥ 7.9	Potential for a destructive ocean-wide tsunami	tsunami information bulletin
		7.6 to 7.8	Potential for a destructive regional tsunami	tsunami information bulletin
		7.0 to 7.5	Potential for a destructive local tsunami	tsunami information bulletin
		6.5 to 7.0 or inland	Very small potential for a destructive local tsunami	tsunami information bulletin
	Inland	≥ 6.5	No tsunami potential	earthquake information bulletin
≥ 100 km		≥ 6.5	No tsunami potential	earthquake information bulletin

Local tsunami: Destructive effects within 100 km of the epicenter.

Regional tsunami: Within 1000 km of the epicenter.

Ocean-wide tsunami: extending across an entire ocean basin.

In this work, the actual acquired data is illustrated in Fig. 1.

The next step in the detection process is to obtain the bottom pressure recorder BPR measurement h_d. This measurement is used to calculate the expected run-up as per

$$\frac{h_s}{h_d} = \left(\frac{H_d}{H_s}\right)^{\frac{1}{4}}. \quad (1)$$

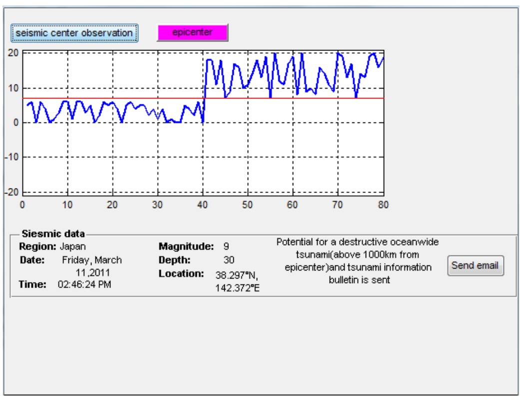

Fig. 1 Aquired data for this research

Then, based on the chart depicted in Fig. 2, the bulletins sent earlier are updated corresponding to the appropriate values of the calculated run-up, and then the updates are sent by email to the emergency authorities.

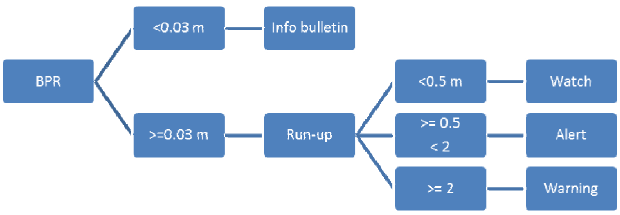

Fig. 2 Decision tree based on BPR measurement

The epicenter is found using the triangulation method as shown in Fig. 3 and a "warning" is issued based on the BPR measurement.

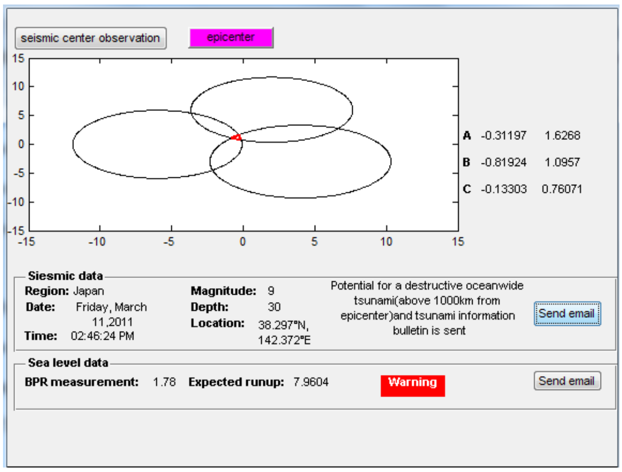

Fig. 3 Triangulation method to locate the epicenter and a "warning" is issued based on the BPR measurement level

The final step of the tsunami detection is to obtain the sea level data recorded by the tide gages located at the shore and the actual run-up, then to use these detected or measured values get the values of the expected maximum wave run-up and of the inundation using the mathematical model

$$H_{r\max} = 2.83 h_s^{1.25} \cot B, \quad (2)$$

where h_s is the wave height at shore calculated earlier, and B is the slope of the seabed (degrees).

Finally, the bulletins are updated depending on the results of the tide gages, and the final bulletins are sent to the emergency authorities to confirm the existence of a tsunami and upgrade the warnings in case they were issued or to cancel any previous warning issued. The updates, i.e. confirmation and cancellation and upgrade are done based on the chart illustrated in Fig. 4.

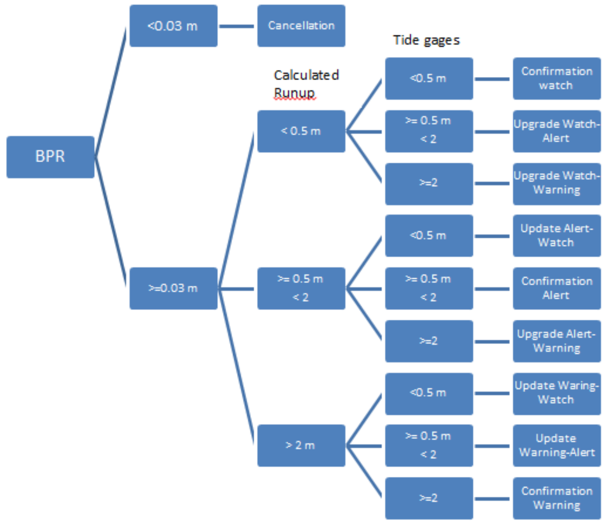

Fig. 4 Decision guide for confirmation, cancellation, or upgrade updates.

Fig. 5 shows a simulation of the system in which the measurements from the tide gages are processed according to 3 sequential options: "acquired", "actual run-up", and "expected inundation".

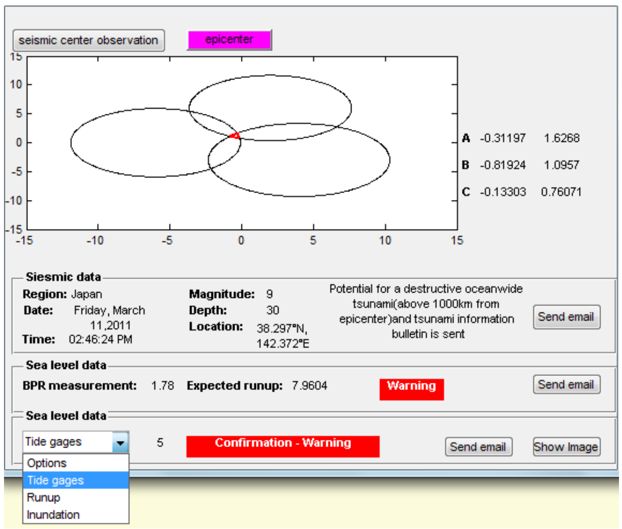

Fig. 5 An actual system simulation

B. Satellite SAR Image Processing

The tsunami monitored regions are remotely sensed using synthetic aperture radars (SAR) [12]-[15]. SAR images suffer from speckle noise, which is a target-induced scattering noise. This necessitates the use of filtering schemes to reconstruct the corrupted speckled images, which appear to human observers as granular images.

Various filters are used to reduce speckle noise [16]-[18]. In this work, we apply 6 types of filters (arithmetic mean, median, maximum, minimum, Wiener, midpoint) to obtain a better SAR image of the location of a tsunami, which are: filters. Fig. 6 illustrates an actual simulation of a speckled SAR image for the affected tsunami area, which was enhanced using a Wiener filter as shown in Fig. 7.

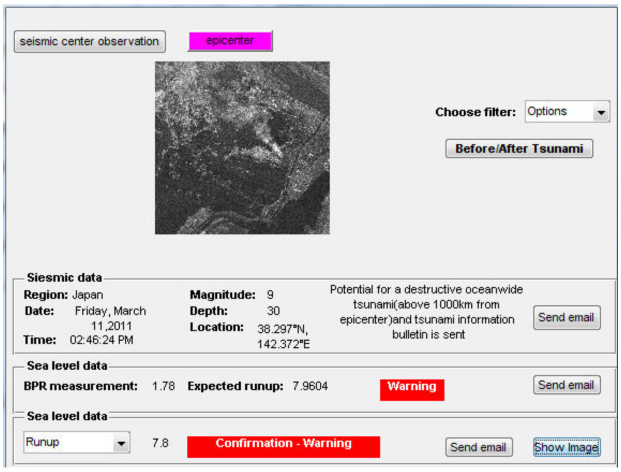

Fig. 6 Simulation of a speckled SAR image for an affected tsunami area

Fig. 7 Wiener-enhanced SAR image of the affected tsunami area

Following enhancement, a post-tsunami damage extent study is conducted. This is done by retrieving an original SAR image of the same area where the tsunami struck, and processing both pre- and post- tsunami images. As illustrated in Fig. 8, the images are mapped into black-and-white binary, where white areas represent damaged fields. A differential (error) image is generated by calculating the difference between the two images where the unaffected fields are highlighted in black. Once these images are generated, the percentage of damages is calculated using the differential image. In this specific simulation, the percentage damage was found to be 54.45%.

IV. Conclusions and Future Work

In this research, we proposed a system to enhance existing tsunami detection and warning systems. This was done by first simulating an automated and miniaturized model of such a system. The automated model was followed by an image enhancement study of SAR acquired speckled images of affected tsunami regions. It was found that the Wiener filter is more suitable for post-tsunami image enhancement, thus enabling a more accurate analysis of a damage extent study of the affected areas. In our particular simulation, the percentage damage was found to be an astounding 54.45%.

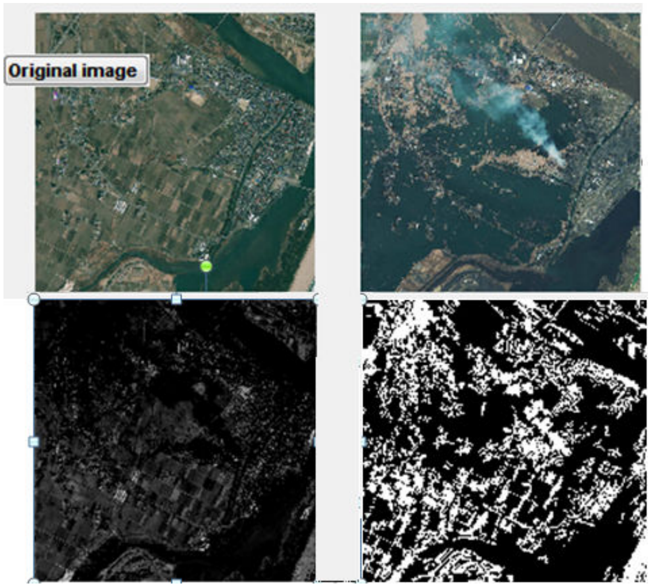

Fig. 8 Post-tsunami damage extent analysis

For future work, we propose improving the communications infrastructure of the tsunami warning system using fiber optic cables for underwater networks that enable real-time monitoring of selected ocean areas and remote configuration and interaction with onshore centers and operators.

Suggestions for additional communication improvement include migration to pure IP-based network, especially for the GTS distribution system for tsunami warning systems, which still operates using obsolete X.25 protocols. The migration to pure IP becomes possible by utilizing directly connected routers, as well as TCP/IP based application services, such as TCP sockets or File Transfer Protocol (FTP). In order to move to pure IP, it is necessary to modify MSSs at each Centre to make use of TCP/IP services such as FTP and TCP sockets.

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References

[1] W. M. Adams, J. M. Jordaan, "Tsunamis and tsunami warning systems," in J. M. Jordaan & A. Bell (Eds.), *Hydraulic Structures, Equipment and Water Data Acquisition Systems*, Vol. 1, pp. 238 – 261, 2011.
[2] Australian Government Bureau of Meteorology, *Tsunami Facts and Information*, Sept.18, 2011.
[3] G. Bugliarello, "Tsunami simulations and numerical models," *Systems Challenges on a Global Scale,* Vol. 35, No.2, 2005.
[4] D. Chang-Seng, "Seychelles progress report towards a Tsunami warning system in the Indian ocean," 2006.
[5] DART, "Deep-ocean assessment and reporting of tsunamis description," National Data Buoy Center, May 6, 2011.
[6] Envirtech, "Technical specifications of underwater module," Sept. 3, 2011.
[7] K. Horsburgh, L. Bradley, M. Angus, D. Smith, E. Wijeratne, and P. Woodworth, "High Frequency Sea Level Recording For Tsunami

Warning and Enhanced Storm Surge Monitoring at UK Sites," *Natural Environmental Research Council Open Research Archive*, 2010.

[8] W. Morissay, "Tsunamis: Monitoring, Detection, and Early Warning Systems," *The Library of Congress Congressional Research Service*, Washington DC, 2005.

[9] R. Stosius, G. Beyerle, M. Semmling, A. Helm, A. Hoechner, J. Wickert, and J. Lauterjung, "Tsunami detection from space using GNSS reflections: Results and activities from GFZ," *Geoscience and Remote Sensing Symposium* (*IGARSS*), pp. 3047 – 3050, 2010.

[10] Y. Teshirogi, J. Sawamoto, N. Segawa, and E. Sugino, "A proposal of tsunami warning system using area mail disaster information service on mobile phones," *Advanced Information Networking and Applications Workshops*, *IEEE International*, pp. 890-895, 2009.

[11] *Forecast Inundation Models*, NOAA Center for Tsunami Research, May 6, 2011. (nctr.pmel.noaa.gov/forecast_inundation_models.html)

[12] J. Dubois and O. Abdul-Latif, "SVM-Based Detection of SAR Images in Partially Developed Speckle Noise," *Transactions on Engineering, Computing, and Technology*, Vol. 12, pp. 139-143, 2005.

[13] J. S. Daba and M. R. Bell, "Synthetic-Aperture-Radar Surface Reflectivity Estimation Using a Marked Point-Process Speckle Model," *Optical Engineering*, Vol. 42, No. 1, pp.211-227, January 2003.

[14] J. Dubois, "Segmentation of Speckled Ultrasound Images Based on a Statistical Model," *Proceedings of the 16th International EURASIP Conference BIOSIGNAL 2002*, Vol. 16, Brno, Czech Republic, June 2002.

[15] J. Daba, "Improved Segmentation of Speckled Images Using an Arithmetic-to-Geometric Mean Ratio Kernel", *International Journal of Computer and Information Engineering*, Vol. 1, No. 4, pp.218-221, 2007.

[16] J. S. Daba and M. R. Bell, "Estimation of the Surface Reflectivity of SAR Images Based on a Marked Poisson Point Process Model," *IEEE International Symposium on Signals, Systems, and Electronics*, San Francisco, USA, October 25, 1995.

[17] J. S. Daba and M. R. Bell, "Segmentation of Speckled Images Using a Likelihood Random Field Model," *Optical Engineering*, Vol. 47, No. 1, pp. 017005-1 to 017005-20, Jan. 2008.

[18] J. S. Daba and M. R. Bell, "Synthetic-Aperture-Radar Surface Reflectivity Estimation Using a Marked Point-Process Speckle Model," *Optical Engineering*, Vol. 42, No. 1, pp.211-227, January 2003.