GPS Based Measurement for Earlier Tsunami Warning System

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***Abstract*-A promising method of detecting destructive forces is of vital importance in protecting mankind from natural calamities. In this regard, Global Positioning System (GPS) in addition to seismic data may be considered as a reliable option in sensing imminent tsunamis and their destructive intensities accurately, while minimizing the frequency of false alarms. GPS stations can provide signals about the ground intensity patterns and facilitates continuous monitoring as frequently as every few seconds. Real Time Kinematic-Global Positioning System (RTK-GPS) is considered to be the most promising GPS techniques due to its reliability and accuracy. In the present study we have used RTK- GPS to find the elevation difference in the detection of tsunami. Comparison is done between tsunami height data obtained from coastal tidal stations/offshore wave stations by using green's law with data obtained from RTK-GPS buoys. Also using the data from seismometers the epicenter is detected, and from the coastal GPS stations near the epicenter, sea floor displacements that precede a tsunami are inferred. Another added advantage of this method is that it also produces a reliable estimate of the destructive potential of a tsunami within minutes of detection before tsunami reaches the coastal areas. By using this method accurate representations of historical tsunamis were well documented and ground motion measurements were available. By developing a global tsunami warning system utilizing an expanded network of coastal GPS stations may be effective in detection of tsunamis.**

Keywords-RTK-GPS; green's law; elevation difference; seismometers; sea floor displacements.

I. INTRODUCTION

One of the most horrible natural disasters on the earth is tsunami which have the wavelength of hundreds of kilometers, commonly considered as shallow water waves [1] kills many people every year. It also contains incogitable powerful energy rushes to the coastline and shore. It is also called as killer wave. Earthquakes beneath the seafloor often happens by the movement of two continent plates generate tsunamis [2]. Nowadays with the help of technology the tsunami can be detected and renewable forecast is made to reduce the loss. Most of the tsunami were caused by volcano, landslide happening under sea and under ocean earthquake happened by the movement of plate tectonics and its crushing each other. Tsunami Early Warning System (TEWS) is a tool for analyzing the wave height, wave velocity, depth and detecting the time of tsunami arrival. Tsunami Warning System also calculates at what time tsunami arrives, the wave runs up and makes a flood on the coastline. To minimize the impact of tsunami disaster, TEWS is built [3].

In the year of 2004, a huge tsunami generated by the earthquake killed about 2,30,000 people. The earthquake's magnitude is seems to be quite unreliable because of the indication of the destructive potential of a tsunami. According to the result declared from the alarm session unit founds to be the same magnitude both in the 2004 Indian Ocean earthquake and 2005 Nias (Indonesia) earthquake. A huge tsunami generated because of the earthquake occurred in Indian Ocean 2004, whereas 2005 Nias (Indonesia) earthquake does not lead to tsunamis. The result declared from the alarm session unit was not considered to be highly infallible, thus the false alarms were issued worldwide in between 2005 and 2007, which result in economic and societal effects. The permanent co seismic deformation of the Earth's surface can be measured by GPS [4]. In order to reduce false alarms we are using one of the most important GPS technique i.e. RTK-GPS to find the elevation difference to detect tsunami in order to improve GPS accuracy. The data obtained from Real Time Kinematic-Global Positioning System (RTK-GPS) buoys is used to compare tsunami height obtained by offshore wave stations and coastal tidal stations using green's law. To estimate the reliable tsunamis height for the coastal points, green's law calculation are applied to the tsunamis height at forecast points. RTK-GPS buoys are typically installed within several kilometers of the coast. The ratio of initial tsunami height observed at a coastal tidal station to that observed at an offshore station was found to be approximately proportional to the fourth root of the ratio of the sea bottom depths to the mean sea level at the respective offshore and coastal station. This approximation can also be applied to maximum tsunami amplitudes. Tsunami height ratio and potentially increased leading time to issue tsunami warning are the two major issues needs to be developed in an integrated approach to address the limitations of an existing approaches. It will enable the tsunami initial height to be forecast using detected initial tsunami height from the offshore station by real time applications such as sea bottom pressure gauges of RTK-GPS buoys. Teruyuki Kato et al [5] describes RTK-GPS system installed on a dual buoy such as support buoy and sensor buoy and it is much more robust and cost effective. The acquired data were stored and then processed in GPS receiver which is installed on the support buoy. These data are processed using RTK software within the receiver and using 429 MHz radio transmission, it is transmitted to the land base; the data which is transmitted are monitored and stored in the PC at the base station. So it would be a practical limit for several kilometers from buoy to base station in order to achieve an accuracy of several centimeters. Mohd Effendi Daud1 et al.[6] discussed about to provide a movement of a GPS buoy relative to a base station with a base line length of 500 Km has been monitored in quasi real time mode. Bernese 5.0 Software (BSW) for GPS data analysis, in order to conduct long baseline quasi RTK-GPS analysis especially with a moving object (GPS buoy), developed new methodology called "windowing processing method" to allow automatic processing at preferred intervals using Bernese Processing Engine (BPE) module with BSW. Teruyuki Kato et al.[7] discussed to provide a buoy is a self contained GPS data collection and it is designed to be deployable as an autonomous platform. This system consists of a GPS equipped buoy and a GPS base station and they used single buoy in order to keep stable in the open ocean for the long term. Here positions are generated by the current system relate to the position of the GPS antenna of the buoy which is located at the top of the buoy. In order to study the relation of this position to the actual surface height of the ocean, they have equipped the buoy with additional sensors such as vertical accelerometer and tilt meter. Yanming Feng, Jinling Wang [8] describes about the Differential GPS (DGPS), Precise Point Positioning (PPP), Single Point Positioning (SPP) and RTK solutions these are the various types of positioning and it also describes about the useful performance characteristics for Position Estimation (PE) solutions in the RTK context and carrier phase Ambiguity Resolution (AR). Commercial RTK systems provide technical specifications to users; so that users can decide which products to use to meet their performance requirements. Commercial RTK system can be tested by the suppliers and users against the given parameters through extensive field experiments under the observational conditions. Weniza [9] describes regression analysis was performed by using observed tsunami height at offshore and coastal tidal station. They calculated tsunami height at forecast points at which water depths are about 50m and then tsunami heights at forecast points are converted into tsunami height at coastal points by applying green's law under the assumption that water depth at coastal point is 1m. Teruyuki Kato [10] compares tsunami records and it suggests observed time of tsunami arrived about half an hour later than the predicted time of tsunami using numerical simulation. The frame work of this paper described about the tsunami detection system is employed with RTK-GPS technology with an accuracy of few centimeters and it also calculates tsunami height at nearby coasts can potentially be forecasted with equal accuracy by using green's law.

II. EXISTING SYSTEM

The GPS buoys developed in (GITEWS) German Indonesian Tsunami Early Warning System prove the suitability of using GPS technology in tsunami warning system. GPS derived offshore sea level time series provides amplitudes and correct time arrival of tsunami and thus benefit the reliability of the whole tsunami warning system and the threshold of tsunami wave heights for GITEWS GPS buoys is between 5cm and 10cm. For the offshore Indonesian area towards the Indian Ocean, destructive tsunamis at the source area may have several decimeters of initial tsunami heights. Thus the amplitudes which are expected found to be much larger than the GPS buoy detection threshold. With the new technological developments in processing and real time networks, this situation is improved by using one of the most important GPS technique i.e. RTK-GPS to detect the tsunami in order to improve GPS accuracy and it also compares tsunami height data obtained by offshore stations and coastal tidal stations by using green's law.

A. Issues in Existing System

- Producing much false alarms
- Potentially increased leading time to issue tsunami warning
- Difference in elevation is not considered.
- calibration is not achieved for tsunami warning system
- RTK-GPS buoy should improve the accuracy of tsunami database

III. PROPOSED SYSTEM

The tsunami detection system currently employed with RTK-GPS technology with an accuracy of a few centimeters by relative positioning and it also monitors a moving platform in real time. If GPS antenna is situated at the top of a buoy floating on the offshore ocean surface, while another antenna is situated at a ground base station near the coast as shown in Figure 1. A sampling frequency of 1Hz is used to monitor the sea surface changes. The data obtained at the buoy is transmitted to the ground base station using radio and a baseline analysis is made in real time by a PC using both the buoy data and the data taken at the base station. Assuming that the coordinate of the base station is known, the precise position of the buoy can be determined to better than a few centimeters of accuracy. Only the buoy's vertical motion as well as other short period wind waves is important for tsunami detection. The determined position of the buoy is not only used for the case of a tsunami but also for all kinds of sea surface changes including wind waves, tides, etc.

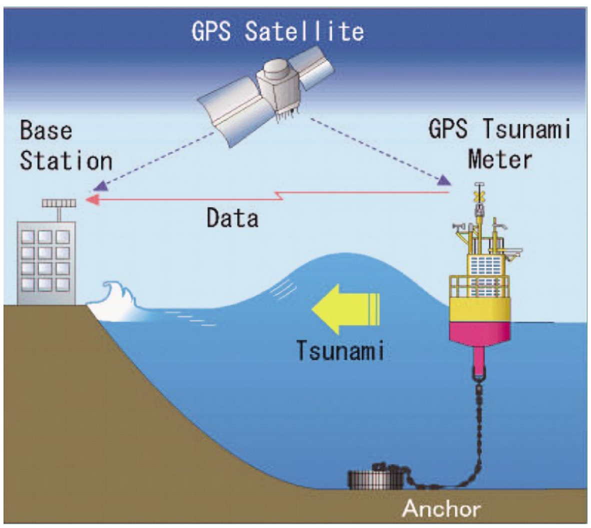

Figure 1: RTK-GPS is employed together with radio transmission for detecting tsunami [10].

The system mentioned above consists of a GPS equipped buoy and a GPS base station. The buoy is a self contained GPS data collection station and it is designed to be deployable as an autonomous platform. The height of the buoy is more than 13m and weight is about 10 tons. The GPS buoy system uses RTK-GPS which requires a land base for the precise positioning of the buoy. This limits the distance of the buoy from the coast of 20Km. Establishment of the buoy further from the coast is truly important to achieve a longer lead time for evacuating nearby coasts. At the base station, the data from the buoy is combined with the data collected by a fixed land based GPS receiver in real time. Using radio transmissions the data is processed and then transmitted to the land base. At the base station the data which is transmitted are monitored and stored in the PC. There is no correction for ionospheric or tropospheric effects could be applied, when the data is processed. The buoy positions are then transmitted by acoustic modems and the position generated by the current system is related to the position of the GPS antenna of the buoy, which is located at the top of the buoy. A small electric power consumption is used for data transmission since transmission rate is limited to 4800 bps, only GPS data is transmitted to the base station; while other data are stored in the data logger equipped in the buoy. This system uses a single frequency RTK so that the feasible baseline distance is only several kilometers from the coast.

Thus in this experiment to achieve an accuracy of several centimeters, it would be practical limit for few kilometers from buoy to base station. Some filtering technique such as Fast Fourier Transform (FFT) can be applied directly to the RTK, in order to differentiate tsunami waves from wind waves

IV. HARDWARE DESCRIPTION OF PROPOSED SYSTEM

The key requirement for the accurate measurement is pressure for many under water observation and construction activities. For the primary observation data, pressure measurement is used in tsunami detection, wave and tide gauges.

A. Bottom Pressure Recorder (BPR)

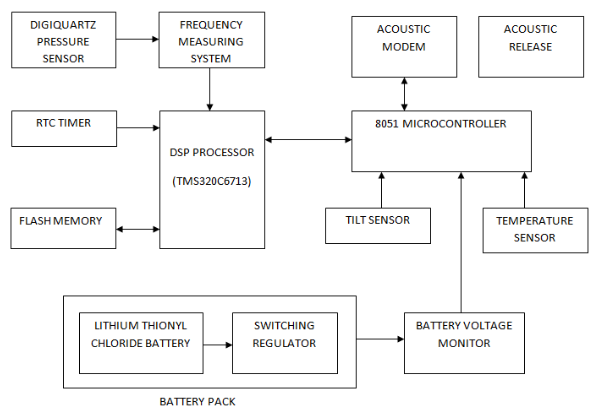

Figure 2: Block diagram of BPR

Quartz resonator technology employed in pressure transducers have been successfully used in one of these applications such as underwater systems which requires the stability, accuracy and highest resolution. To detect tsunami possibly from great ocean depths with the lowest noise, highest resolution and most accurate instruments available today is digiquartz pressure sensor. The transducers are based on the vibrating quartz crystal technology, highly stable, and inherently digital. To read pressure from Digiquartz transducers you will need a signal processing system capable of reading frequency. So the output of the pressure sensor is given to DSP processor (TMS320C6713) through RS232. In which tsunami program is dumped in the processor. In order to store the previous pressure data flash memory is connected to DSP processor as shown in Figure 2. The output of the processor is given to the 8051 microcontroller in which it controls the processor, acoustic modem and TCM 2.5 compass. TCM 2.5 compass is connected to microcontroller allows detecting orientation or buoy inclination. RTC timer is to click for every 15 seconds. The pressure data which is calculated is transmitted through acoustic modem from tsunameter to surface buoy which is collected by another acoustic modem present in surface buoy.

B. Surface buoy

Figure 3 describes about surface buoy. The data from the BPR is collected by the data logger via GPS. These data are sent to the base station through INSAT and INMARSAT modem.

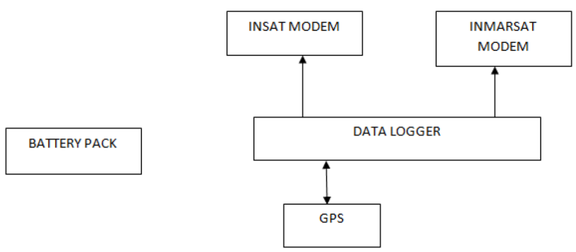

Figure 3: Block diagram of surface buoy

The term data logger is often used to describe a standalone data acquisition system and self contained device. It is comprised of a number of digital and analog inputs which is monitored and then a result of these inputs is stored in local memory. A data logger is more typically deployed as standalone devices while connecting to a host PC over serial port. Once the unit is programmed with the application , unit is placed in location, the logging application is started by connecting the various input and output signals.

C. Hardware of Data logger

An attractive alternative to either a data acquisition system or recorder is data logger which is used in many applications. When data logger is compared to a recorder, it has the ability to accept a greater number of input channels with better accuracy and resolution. The hardware of the data logger as shown in Figure 4 consists of a four layer circuit board. Its size is 132x100 mm. The internal 5V power source is provided by a galvanically isolated DC/DC converter with an effectiveness of 82%. 9V to 36V DC are accepted as primary voltage. The isolation voltage amounts 1500V DC. The 32 bit CPU with integrated flash memory meets the requirements for extended temperature range at 16MHz clock frequency. Application programming can be done using the ISP interface or by a flash loader application permitting firmware download at the serial port 1. The flash memory of the CPU can be reprogrammed 1000 times. To meet shock and vibration requirements the real time clock RTC-8564 (EPSON) with integrated 32 kHz crystal is used. As an option the data logger board may be equipped with a long life lithium battery to power the real time clock during board power loss and which enables time keeping up to 5 years.

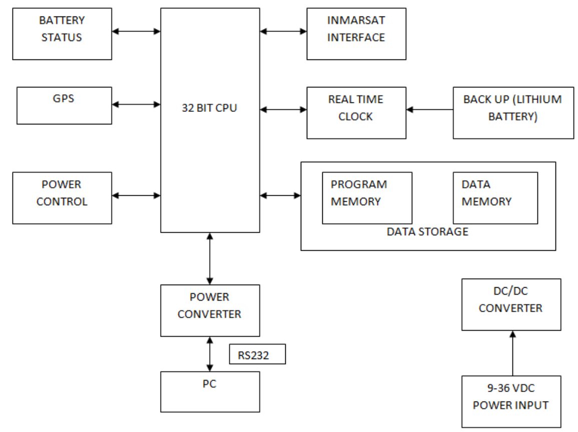

Figure 4: Block diagram of data logger

An intelligent power monitor chip handles monitoring of internal voltage and reset control. The recorded data is stored into ferroelectric RAM chip. Guaranteed storage time in powerless state is 10 years. Standard mounting uses four of these devices with 32k x 8bit memory which compose the 1024 Kbit overall capacity. The serial interface used as data input as well as the serial interface used to read out stored data are RS 232 complaint and accessible by DB-9 connector. Allows the data logger to be permanently connected to a network so that any PC on that network can download the data.

V. METHODOLOGY

One equation derived from Green's law was tested to determine if it could explain the observed data on initial tsunami heights and maximum tsunami amplitudes. Here H is supposed to be an offshore initial tsunami height or maximum tsunami amplitude under the assumption of no influence by the reflected tsunami wave at coast lines. If the doubled effects of total refection at a coast line and amplification effects due to water depth differences are considered, based on green's law initial tsunami height or maximum tsunami amplitude at the coast should be approximated by

$$Hc = 2H\,(ho/hc)^{1/4} \qquad (1)$$

Where Hc is initial tsunami height or maximum tsunami height at the coast, ho is the water depth at an offshore as measured from the mean sea level, and hc is the sea bottom depth near a coastal tide gauge as measured from the mean sea level. Based on the data, equation to be tested in this paper is

$$Hc = \alpha Ho\ (ho/hc)\ ^\wedge\ 1/4 \qquad (2)$$

Where Hc is the corrected height of the initial tsunami or maximum tsunami height and α is defined by

$$\alpha = 2/\ (1 + k) \qquad (3)$$

Because of its definition, $-1< k <1$ should be satisfied; therefore, $\alpha>1$ is expected. The assumption that the initial tsunami height should be partially affected by the reflected wave was based on the following evidence recorded by both an offshore NOWPHAS sea bottom pressure gauge and a coastal tide gauge at Chile 2010 earthquake tsunami from each waveform. The derived regression lines are

$$Hc, init =1.005Ho, init\ (ho/hc)\ ^\wedge 1/4 \qquad (4)$$

and

$$Hc, max=1.180Ho, max\ (ho/hc)\ ^\wedge 1/4 \qquad (5)$$

as derived in the paper [9] where Hc,init and Hc,max are the tsunami initial height and maximum tsunami height at the coast and Ho,init and Ho,max are the tsunami initial height and the maximum tsunami height at an offshore station. Thus Eq. (4) properly corrects and explains the relationship between the initial tsunami height data recorded by offshore and coastal sites NOWPHAS wave stations and RTK-GPS buoys and Eq. (5) explains maximum tsunami height in same way. Proportional constants (α) are 1.005 for initial tsunami height and 1.180 for maximum tsunami amplitude Eqs. (4) and (5). The standard deviation of log scaled residual error of initial tsunami heights and maximum tsunami amplitude are 0.156 and 0.161 as given in the paper [9]. Thus the formulas derived in [9] paper (Eq. (4)) can correct initial tsunami height data at offshore NOWPHAS wave stations and RTK-GPS buoys, so that the data can be treated in the same way as data recorded at a nearby coastal tidal station. This correction brings the difference between the two data sets to approximately 30%. If the height of the offshore tsunami at these offshore observatories can be obtained in real time, tsunami height at the nearby coasts can potentially be forecasted with equal accuracy by applying the formula.

VI. RESULTS

Two tsunami events sampled by RTK-GPS buoys for which the data is recorded with sufficient clarity to use in the discussion of tsunami height: 2010 Chile and Mutsu ogawara port. The data which is recorded by RTK-GPS buoys and NOWPHAS wave station needs to correct the tsunami initial height and tsunami maximum height seems to fit the same regression lines. Eqs. (4) and (5) is used to correct tsunami observation data recorded by RTK-GPS buoys and NOWPHAS wave stations, with the aim of predicting tsunami initial heights and tsunami maximum heights at nearby tidal stations. If the initial height of tsunami from RTK-GPS buoys can be detected in real time, the real time application of Eq. (4) enables us to forecast initial tsunami height at the nearby coast. Such an advanced tsunami forecast may probable be achieved in the near future because of RTK-GPS buoys. The recorded data for tsunami events and calculated initial and maximum tsunami height observed at an offshore station using the equation (4) and (5) as derived in the paper [10].

Table 1: Calculation of *H*c using the parameters.

	45 meter		300 meter	
	Init	max	Init	max
ho	45	45	300	300
hc	10	10	10	10
Ho	1	4	0.7	1.5263
α	1.005	1.180	1.005	1.180
Hc	1.130625	5.31	5.27625	13.5077

VII. CONCLUSION

In this paper, RTK-GPS technology based tsunami detection system was developed with an accuracy of a few centimeters by relative positioning, it monitors a moving platform in real time and it also obtains initial and maximum tsunami height data at offshore stations and coastal tidal sites of RTK-GPS buoys and NOWPHAS wave stations (Table 1). The ratio of initial tsunami height or maximum tsunami amplitude observed at a coastal tidal station to that at the offshore site was found to be proportional to the fourth root of the ratio of the sea bottom depths from the mean sea level at the offshore sites to the coastal stations Eqs. (4) and (5). RTK-GPS buoys and an offshore NOWPHAS wave station successfully detects tsunami initial height in real time, the Eq. (4) is used to achieve high accuracy , better efficiency and to realize real time forecasting of initial tsunami height at a nearby coast.

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