Developing Measurement System for Sea Waves Height

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***Abstract*—The study of underwater acoustic channels is important for applications such as telemetry between underwater vehicles. There are fundamental limitations associated with underwater communication channels in common with other communications media (i.e, spreading noise, Doppler shift of 1%, signal fading and multipath propagation). These limitations, multipath propagation caused by reflections from the sea surface and sea floor is particularly extreme. An important consideration when dealing with the multipath reflections is the movement of the sea surface, as this can affect the way in which acoustic signals travel. It is therefore necessary to have a good record of the surface conditions during experiments using acoustic communications. There are various methods and transducers that can be used to measure the surface variation. The developed system described in this paper (stepped-contact staff and a MATLAB simulation) is capable of measuring small and high frequency surface waves to a high degree of accuracy. It can operate in water with high impedance (up to 700kΩ per 5) and consists of a simple design. A DC Whetstone Bridge was used to modulate the sea surface movement, a voltage follower operational amplifier was used due to the high impedance of the output of the bridge and a TC500EV A/D converter was used with a micro-controller interfaced to a PC using its RS232 serial port. A MATLAB program simulated and plotted the variation of the depth of the wave staff in centimetres.**

***Keywords*— Ocean Waves; Single Point Wave Observations; Spatial Wave Measurements**

I. INTRODUCTION

The changes of the sea environment such as fluctuation of the sea waves is very important information for marine activities, deep-sea development, fisheries, and marine resource transformations [1]. Continuous development in the fields of deep water and open marine areas faces great challenges for marine engineering, especially this environment, which needs accuracy in installation and speed of operation in deep-sea pipelines, as well as continuous improvement with the requirements of increasing development [2] [3].

Marine vehicles are very sensitive to environmental changes during pipeline installation. It is of the utmost importance to study the marine environment with high accuracy during the installation and operations, which is greatly assist in planning the installation of pipelines, as there are many methods for monitoring environmental changes in marine engineering during pipeline installation [4]. The monitoring system was developed during the laying of the offshore pipeline in terms of measuring the movement of the ship, the level of overhead tension and heading profile, in order to perform all these operations and install the pipeline accurately and safely [5].

A cable-type wave monitoring system was used to measure the height of the shallow water wave, however these wave height observations were discontinuous and the algorithm of this system was operating on an internal area of less than 100 meters [6]. An operational wave monitoring system has been used for a Mediterranean sea to predict the wave fluctuation up to five days in advance when run the system once a day [7].

II. DESCRIPTION OF THE SEA WAVES

A sea wave is described by its height and length . Wave height is defined as the height of the wave from the wave top called the wave crest to the bottom of the wave, called the wave trough. The wavelength is defined the horizontal distance between two successive crests or troughs, and during the storms the wave height increases while the wavelengths decreases [8].

A. Multipath Phenomena

A major practical limitation in the design of an underwater acoustic telemetry system is multiple path interference. These multipath are caused when the acoustic signals travelling from the transmitter reach the receiver by several different paths. The major sources of multipath propagation as they affect underwater position fixing operations are reflection from the sea, surface, reflection from the seabed, double reflection from the sea surface and seabed, and reflection associated with man-made structure.

Recent signal-recognition methods which have been introduced to overcome this problem, by isolating the direct ray, are differential filtering, time integration filtering, phase flip in the interrogation signal, and correlation techniques.

The transmission of signals to transponders from interrogating units also must be unambiguous, especially when either switching off a transponder or activating its self-release mechanism.

There are several techniques for acoustic telemetry systems such as pulse code modulation (PCM), pulse duration modulation (PDM) , pulse position modulation (PPM) , and frequency shift keying (FSK) which have been developed .

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The multipath interference is of course worst with omnidirectional transducers. Thus several manufactures now supply transducers with a hemispherical beam to reduce multipath. Other suggestions to reduce multipath effects have been to produce either hydrophones or transponders with narrow conical beams. The latter system using seabed transponders with microprocessor-controlled pencil-beams for tracking the transducer.
This system could be extremely useful for underwater navigation on large complex underwater platforms where a myriad of surfaces contribute to multipath acoustic propagation [8].

B. Acoustic loss at the sea surface

Multipath propagation exists due to reflections from the sea surface between the transmitter and receiver. Surface reflection can generally be characterized by their relatively large separation in arrival angle from the direct path at the receiver and the resulting time delay, due to the increase in propagation distance under both shallow and deep-water conditions. Propagation paths may appear to be close to the angle of the direct path as in Fig.1.

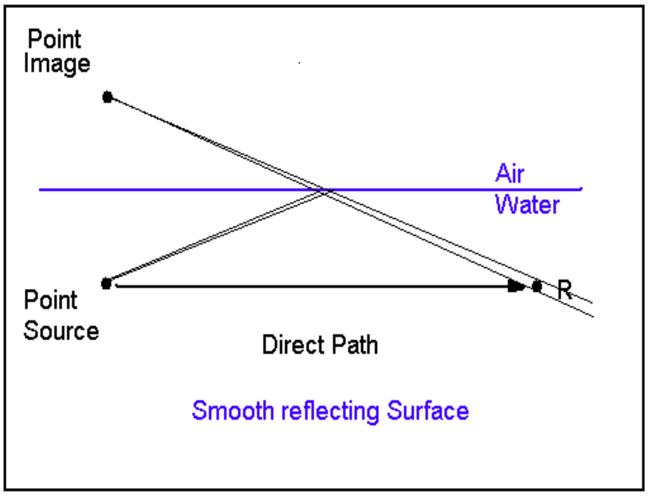

Fig. 1 Smooth reflecting surface

In Fig. 2 the interface is not perfectly smooth. The acoustic rays are reflected in random manner from the rough surface, with the result that the image of the source, as viewed from R, is smeared over an area such that the apparent image intensity is reduced compared with result for a smooth surface. As the interface becomes very rough, diffuse reflection occurs, resulting in a large loss in intensity at R.

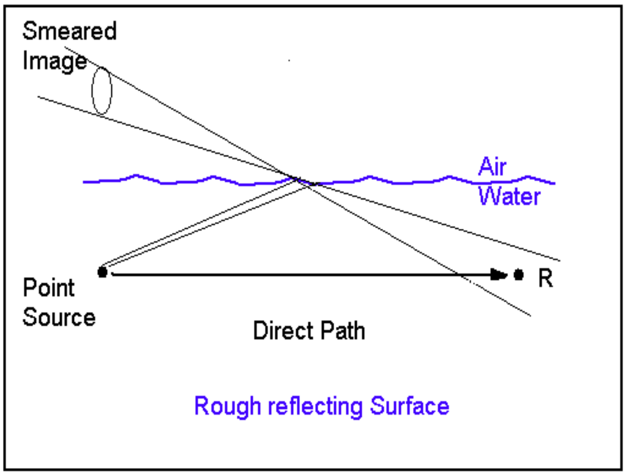

Fig. 2 Rough Reflecting Surface

The expression for acoustic loss caused by reflection from the sea surface as a function of the product of wave height and acoustic frequency [8].

$$\alpha = -10 \log \left(1 - 0.0234 \, (fH)^{3/2} \right) \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

Where:

α : surface reflection loss, *dB*
f : Acoustic frequency, *kHz*
H : Average trough-to-crest wave height, *ft*.

Equation (1) was derived by assuming that the grazing angle is small. In the form shown, the equation should not be used for loss values exceeding *3dB*. Consideration of higher-order terms were neglected in the equation [8].

III. Fixed Instruments Measuring Waves at The Sea-Surface

A. Capacitance-wire gauges

In these, an insulated wire is stretched vertically through the water surface and the capacitance between the wire and the sea is measured. To avoid having to insulate the bottom end, the wire is usually looped over a support and brought back to the top mounting, giving two parallel wires. The capacitance is measured by a circuit using a high-frequency alternating voltage, and it varies linearly with the depth of immersion.
Problems are encountered because of conducting films forming on the surface of the insulation. Even initially non-wettable plastics seem to weather and eventually produce a wettable surface, so that a conducting sheath is left as the sea surface drops. The effect of this can be minimized by using a high a.c frequency, but the optimum frequencies are in the radio bands, and one cannot use them because the radio wavelength has to be long compared to the length of the

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sensor if the 'd.c' capacitance is to be measured. (Tucker & Charnock 1954). They would also radiate radio interference. Further problem is that many insulators absorb some water. Since water has a high dielectric constant (81 at the frequencies of interest), even 0.1% absorption significantly changes the dielectric constant of the plastic, and this absorption varies with time. PVC is particularly bad. The absorption varies with the proportion of the time that the wire is under water and thus the vertical position, leading to nonlinearities. Although capacitance gauges continue to be used, these problems have never been completely overcome, in spite of the availability of wires covered in improved insulating materials [8].

B. Resistance-wire staffs:

In these, two parallel resistance wires are stretched vertically a fixed distance apart. The sea shorts across the bottom of the wires, so that the resistance across the top terminal changes linearly with the wave elevation. It does not matter as far as measuring waves is concerned if it takes a considerable length of the immersed wire to achieve this shorting, since this represents a zero shift, which is constant over the duration of a wave record. Thus, robust wires of quite low resistance can be used. An alternative arrangement is to spiral a resistance wire round an insulating rod with a large earth electrode to provide the return path. Gauges of this type have proved to be unsatisfactory in routine use because more-or-less insulating films form on the surface of the wires, and seaweed or refuse material can become attached. They are still used in model tanks, however, where they can be cleaned immediately before use [8].

C. Stepped-contact staffs

A series of electrodes is mounted on the staff at vertical intervals of typically 7.5cm together with a permanently immersed earth electrode. Alternatively, each electrode can be surrounded by an earthed ring, like a car spark plug. As the sea surface raises it successively shorts out the electrodes, and as it falls they become open circuit. In principle they can be arranged to short out series resistors, or to switch in parallel resistors. In practice the series arrangement seems to have been preferred. This arrangement produced errors due to leakage through the seawater film over the electrode insulation. In the next development, each electrode was therefore arranged to operate a relay, and these relays switched the resistors. In recent developments these relays are arranged in a logical network to give a direct digital output for recording [8].

D. The Baylor wave gauge

This consists of two vertical parallel steel wire ropes each of 12.7 mm diameter separated by 228.6 mm and stretched under tension through the sea surface. They form an electrical transmission line terminated at its lower end by the sea. The impedance of this line is measured at 0.65 MHz, at which frequency it is effectively a pure inductance with an impedance of a few Ohms. These gauges have been widely used on offshore platforms, but have proved to be vulnerable to impact from supply boats etc. Because they need to be mounted well away from the main structural members [8].

IV. Instrumentation and Electronic System

A. The Developed System (Stepped-contact Resistance Staff)

In the developed system a group of contacts are mounted on the staff at vertical intervals of typically 5cm. In the middle of each two contacts there is a ground contact, and a group of resistors (30 resistor) in the designed board connected in series to perform the resistance (Rx) in the Wheatstone bridge. The first node of the first resistor connected to the first contact of the staff from the top and the second node (which is between the first and second resistors) connected to the second contact of the staff (sensor)and so on respectively up to the last node of the last resistor which is connected to the last contact of the staff to perform the lower level of the sensor as shown in Fig. 3. As the water surface raises the contacts successively shorts, and as the water level falls they become an open circuit. Hence the value of Rx decreases and increases respectively.

The value of each resistor equal one mega ohm $1\ M\ \Omega$, and was chosen to be high. This value was chosen to be higher than the impedance between the contact and the ground in the water. Each $1\ M\ \Omega$ resistor represents 5cm on the sensor.

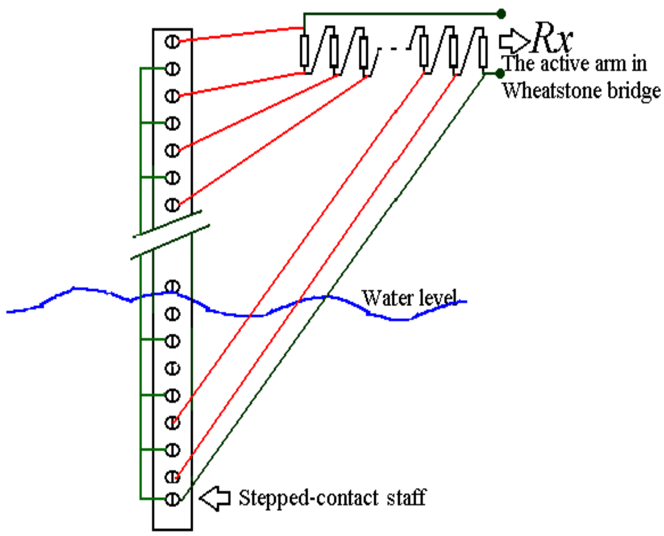

Fig. 3. Stepped-contact Resistance Staff

B. TC500EV Analog to Digital Converter

The T500EV as shown in Fig. 4 is supplied from Telecom company, consists of the TC500 and TC514 A/D converters; a pre-programmed microcontroller, TC520A

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Serial Interface Adapter, a ±3V regulated power supply and user prototyping area TC500EV connects to any RS232 terminal. Typically the host is an IBM PC compatible or other personal computer running a communications program such as Windows™ * Terminal™*, or a dumb terminal. The user supplies a fixed 5.0V power supply and an RS232 cable.

Convenient jumper options allow operation as either a single channel (TC500) or 4 channel (TC514) A/D converter to a maximum of 18 bits (Overrange + Sign + Data). Conversion data can be accessed via the RS232 port, the on-board serial interface adapter (TC520A.

The TC500/514 incorporates an Auto zero and Integrator phase in addition to the input signal Integrate and reference Deintegrate phases. The addition of these phases reduce system errors and calibration steps, and shorten overrange recovery time. A typical measurement cycle uses all four phases in the following order:
Auto zero - Input signal integration - Reference deintegration - Integrator output zero.

Fig.4. TC500EV A/D Converter

C. Operation of Stepped-contact resistance staff

The Fig.5 as shown below, shows the circuit diagram of the developed system. After the system and the other accessories are switched on, then there should be balance of the circuit by changing the variable resistance (R1) until a zero output voltage is achieved which means the sensor is at zero level. After balancing the circuit and the TC500EV's integration time the TC500EV starts converting the variation of the output voltage that represents the water fluctuation from analogue signal to digital signal and sends the data as decimal numbers to a named file in the computer through serial port RS232 using special software for TC500EV to operate its microcontroller. Each 23899 decimal number represents one volt in TC500EV.

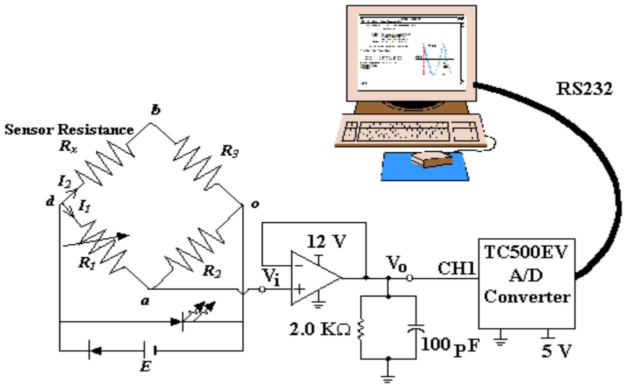

Fig. 5 circuit diagram of the developed system connected to A/D converter

V. Results and Discussion

The sensor was fixed at different levels and the readings obtained are shown below, they show the TC500EV reading, the total resistance of the sensor, the output voltage and the wave height.

D. The immersion at zero level:

After transferring the data that had been taken from the system to the MATLAB program for simulation the results were as follows:
The wave height = 0 cm
The total resistance of the sensor ($R_x = 15 \quad M\Omega$).
The output voltage = 0 volt (this case the bridge in balance).
The graph as shown below in Fig.6 that has been taken after the simulation shows the wave height is at zero level during 12sec.

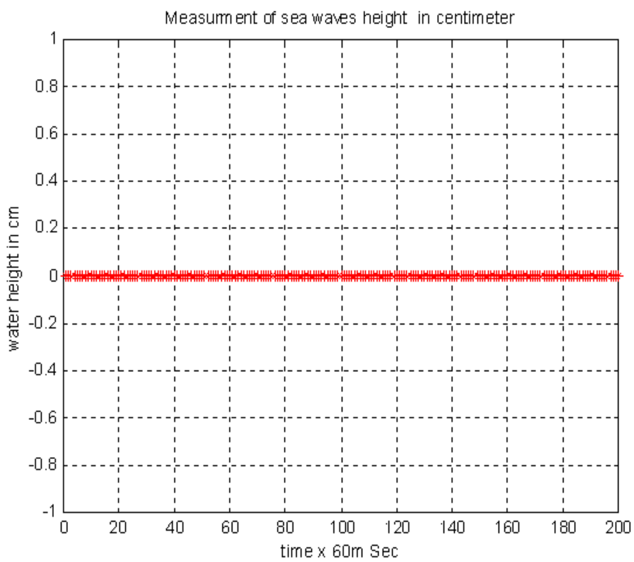

Fig.6 The wave height in zero level

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E. The immersion is 5 cm above the zero level:

When the water level goes up to 5 cm above the normal level (zero level) the output data changes, the output voltage decreases; the total resistance of the sensor decreases and the wave height increases 5 cm. This gives the exact reading of the water level, which is shown below:

The wave height = 5 cm

The total resistance of the sensor ($R_x = 14 \; M\Omega$).

The output voltage = -0.0117 volt (this case the bridge not in balance).

The graph in Fig. 7 shows the water level during 12sec when the water level is at 5 cm level

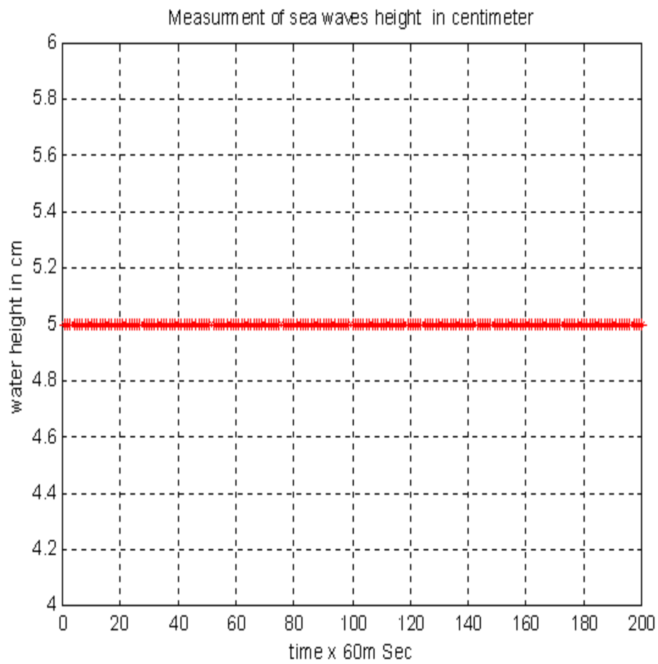

Fig. 7 The wave height is 5 cm above the zero level

F. The immersion is 20 cm above the zero level:

When the water level increases further up to 20 cm above the normal level (zero level) the output data also changes, the output voltage decreases, the total resistance of the sensor decreases and the wave height increases 20 cm. This gives the exact reading of the water level, which is shown below:

The wave height = 20 cm

The total resistance of the sensor ($R_x = 11 \; M\Omega$).

The output voltage = -0.40 volt (this case the bridge not in balance).

The graph in Fig. 8 shows the water level during 12sec when the water level is at 20 cm above the zero level.

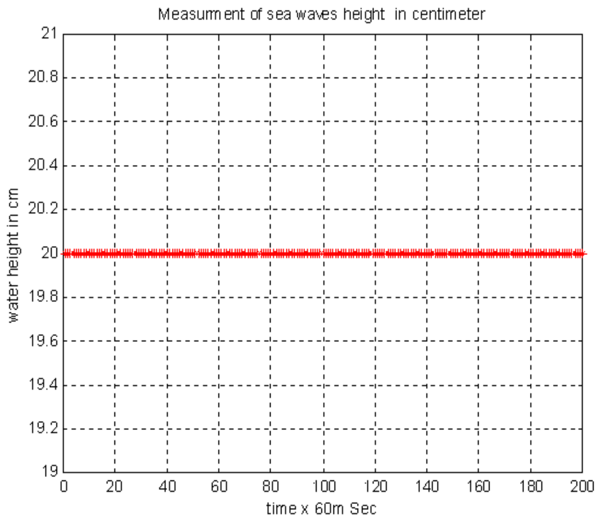

Fig. 8 The wave height is 20 cm above the zero level

G. The immersion is 10 cm below the zero level:

When the water level decreases to -10 cm below the normal level (zero level) the output data also changes, the output voltage increases, the total resistance of the sensor increases and the wave height decreases -10 cm. This gives the exact reading of the water level, which is shown below:

The wave height = -10 cm

The total resistance of the sensor ($R_x = 17 \; M\Omega$).

The output voltage = 0.20 volt (this case the bridge not in balance).

The graph in Fig. 9 shows the water level during 12sec when the water level is at -10 cm below the zero level.

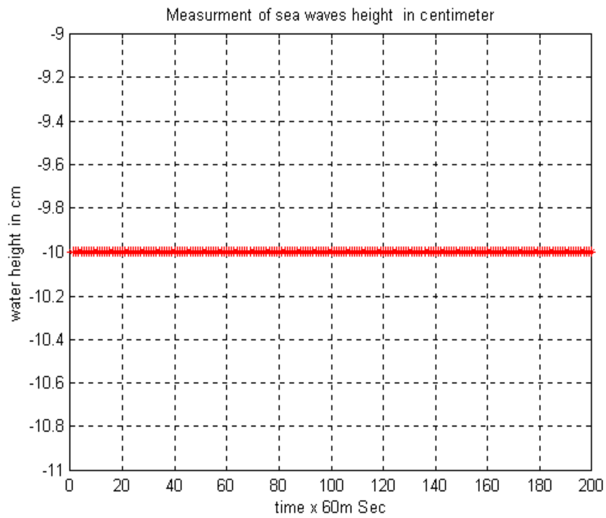

Fig. 9 The wave height is -15 cm below the zero level

H. The immersion is 15 cm below the zero level:

When the water level decreases further down to -15 cm below the normal level (zero level) the output data also changes, the output voltage increases, the total resistance of the sensor increases and the wave height decreases -15 cm.

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This gives the exact reading of the water level, which is shown below:

The wave height = -15 cm

The total resistance of the sensor ($R_x = 18\ M\Omega$).

The output voltage = 0.30 volt (this case the bridge not in balance).

The graph in Fig. 10 shows the water level during 12sec when the water level is at -15 cm below the zero level.

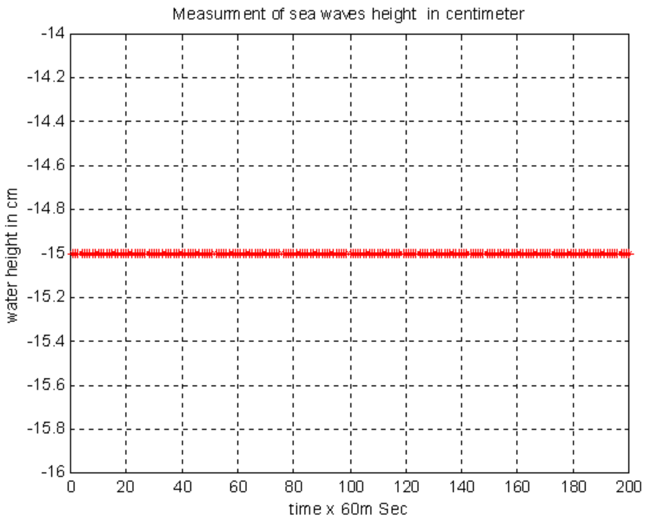

Fig. 10 The wave height is -15 cm below the zero level

I. The fluctuation of water over 12sec:

When the water level fluctuates the output data also changes, increasing and decreasing proportionally to the level of the immersion. This gives an exact reading of the water level.

The graph in Fig. 11 shows the water level over 12sec when the water level is in fluctuation. During this period the water level is between –40cm and –50cm (below zero level) in height.

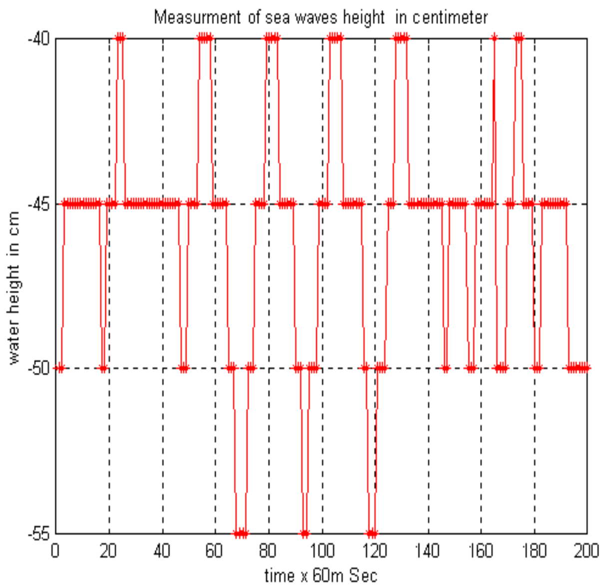

Fig. 11 The fluctuating wave height

VI. CONCLUSIONS

To conclude the results, the sensor was set at zero level as a reference point, and the calibration was made to balance the circuit (i.e the output voltage should be zero), after running the MATLAB program, the result of the wave height was zero, when the immersion was 15cm above the zero level the result in the computer was 15 cm and also the output voltage reading was exactly the same as in the circuit.

The developed system can give a reading of the wave increasing 5cm at a time up to a maximum of 1.5 meters (i.e the accuracy of this system is ± 5 cm). The system can give an exact reading according to the immersion if the water impedance is not more than $700\ k\Omega / 5cm^2$. Unless there is isolation between the contact wires, preventing the wires touching, the system will not give the correct results.

The result of the MATLAB calculation used to determine the wave height was not in real time during the variation of immersion. In order to get different ground, a battery source should be used to feed the Wheatstone bridge, and the mains supply to feed the operational amplifier and /tc500EV.

The quantity of salt in to water makes no change to results, if the impedance of the water is less than $700\ k\Omega / 5cm^2$.

The advantages of the developed system are simple design, low cost, and can be used for laboratory measurements because it gives an exact results and installation is easy.

The disadvantages of it are not suitable for high waves measurements because to increase the capacity of measurements needs a higher number of resistors, the number of wires which are connected from the resistor terminals and the contacts will increase, unless you fix the resistors between the contacts in the sensor itself. However, this method requires the resistor to be isolated from the water to prevent a short-circuiting. The battery life that used to feed the Wheatstone bridge is low and needs to be changed frequently due to high impedance of the sensor staff within the system.

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