Experimental Measurement Of Floating Structure Motion Response Based On The Low-Cost Microcontroller In Towing Tank Laboratory

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EXPERIMENTAL MEASUREMENT OF FLOATING STRUCTURE MOTION RESPONSE BASED ON THE LOW-COST MICROCONTROLLER IN TOWING TANK LABORATORY

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ABSTRACT

The purpose of this study is to find out the results of measurements of floating structure motion response to regular waves using open source microcontrollers produced by wave makers. A direct measurement is carried out in real time using Arduino Mega Microcontroller with an MPU-6050 IMU sensor and HC-SR04 sensor, and the wave maker in towing tank of Ship Hydrodynamics Laboratory, Department of Naval Architecture, Diponegoro University. The floating structures, cylinder and prism hexagon with a diameter and a height of 10 cm, are given a weight that varies according to the desired draft. Each draft is measured the motion response to the same wave. The measuring instrument, MPU-6050, is placed on a floating structure and then the data is transferred via Arduino Mega on each unit of measurement time and then stored on the computer.

Keywords:Arduino, low-cost microcontrollers, measurement, towing tank, response motion

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1. INTRODUCTION

1.1. Background

The use of microcontrollers in all fields is so fast now. There are even some modular robots at relatively affordable prices based on Android and Arduino which can be obtained easily and have internet connection capabilities. For example, Andruino-A1 was used for Educational Mobile Robot in the educational environment, both for teaching in the classroom and for the benefit of the laboratory, even data acquisition equipment in the laboratory by [1].

The use of a computer-based data acquisition system, modular microcontroller, currently uses the open source concept so it is very open for users and developers to develop it further. The design of firmware-based modular devices from a computer-based data acquisition system with low costs is very interesting to be applied to laboratory experiments and applications in industry [2].

The use of Arduino has begun to widely used in the laboratory environment, in addition to the low cost and open source (especially from the Arduino family), the level of accuracy can be accounted. The modular strength of this microcontroller is the ability of the storage system to acquire data directly into storage media without depending on external hardware or software. Also, this open source nature raises a variety of volunteer communities that provide hardware and thousands of scripts for free for various needs of laboratory research projects and industrial development [3].

One measurement system that is quite good in a microcontroller is the IMU system (Inertial Measurement Unit). IMU is a sensor for measurement related to motion. In the field of naval architecture, the measurement of ship movements and ship models in towing tanks still use traditional methods, where to measure ship movements involves the use of large sensor units which usually require cables. This device is not only expensive but difficult and time-consuming to install [4]. The IMU sensor system has also been used to measure the stability of fishing vessels, in addition to the relatively small, simple equipment that can combine with a mobile phone and the results have good accuracy [5].

Towing tank in the Hydrodynamics Laboratory of the Department of Naval Architecture - Diponegoro University, have a relatively small size, so we need relatively small and simple measurement equipment. The current equipment, both supporting and sensor equipment is far from adequate. Some measuring sensor equipment for standard towing tank has a relatively high price. With limited facilities and infrastructure, especially financial, it is necessary to use a modular microcontroller system.

The application of some of these modular microcontrollers on the measurement sensor system in towing tanks is a novelty in this study. The sensors using IMU (Inertial Measurement Unit), with a measurement capability of 6 DOF to 10 DOF, which can then used for 3D tracking systems of floating objects or ship movements as the contribution of this study to science, especially in Naval Architecture.

The IMU sensor system microcontroller as a ship motion measuring device can be applied at the Hydrodynamic Laboratory of the Department of Naval Architecture, which has a relatively small size, low cost, open source, and wireless. The aim of this research is how to apply IMU for motion response measurement of floating structures in towing tanks using an Arduino microcontroller and MPU 6050 as a DOF 6 sensor.

1.2. State of The Art

The conventional or traditional method for measuring ship movements involves the large sensor units which usually require a lot of complicated cables. This device is not only expensive but difficult and time consuming for installation. The cost of the measurement and the equipment used is quite expensive, and not all shipowners, shipyards and academics and practitioners can use it effectively to measure and even monitor the movements of their vessels during the operation. Therefore, it is very necessary to use measurement equipment that is relatively cheaper, simpler and more accurate.

Measurement of ship movements is very helpful to improve the operational stability of the ship and can be used to infer sea conditions using a wave float analogy. This additional information is very important in improving the operational safety of the ship. A new ship motion measurement system that uses Raspberry or Arduino Pi with a wireless module and IMU sensor can measure ship movements or floating objects. The collected data can be stored locally on Arduino or sent wirelessly to the user. Compared to traditional devices, the Arduino microcontroller module is cheaper and easier to install.

The computational ability is quite good especially post-processing data which are traditionally displayed on a computer and separate from the measurement unit and then processed after doing the experiment. Both Raspberry Pi and Arduino can do it without the help of a computer and are carried out in real time right away [4].

Some tests of measurement accuracy using an open-source and low-cost microcontroller Arduino have been widely used, especially in laboratory environments, with quite good results [3]. Also, the use of this open source microcontroller can make measurements such as those made by commercial data acquisition devices such as National Instrument. The accuracy level reaches ± 0.25% FSR for analog outputs, and the differential linearity error is ± 0.5 bits [2].

With this level of accuracy, it can say that low-cost and open source microcontrollers can be used for measurement purposes in the laboratory. Some alternative low cost and open source microcontrollers are currently, among others, Arduino, Gadgeteer, and Raspberry Pi [4]. A specification comparison of some low cost and open source microcontrollers, can be seen in Table 1.

Based on Table 1, the components of the low-cost and open source microcontroller costs are still relatively inexpensive when compared to using the IMU system which is currently built in a ready-made chip, with a price range of more than £ 1000, and even with no cost installation [6]. The three low-cost and open source devices in table 1, Arduino devices have very fast development with the support of voluntary developers.

Table 1 comparisons are of low cost and open source platform prototypes [4].

	Arduino	**Gadgeteer**	**Raspberry Pi**
Model	R3	FEZ Spider	Model B
Price	$30	$120	$35
Processor	ATMega 328	ARM7	ARM11
Clock Speed	16 MHz	72 MHz	700 MHz
RAM	2 MB	16 MB	256 MB
Flash	32 KB	4.5 MB	(SD Card)
Min Power	42 mA	160 mA	700 mA

Dev IDE	Arduino Tool	Visual Studio	ADLE, Linux etc

Arduino hardware consists of open hardware design with the Atmel AVR processor. Arduino boards may be purchased preassembled, Arduino hardware design information is available at http://arduino.cc, for those who want to make or modify their projects. Some third parties have developed a large number of Shields (additional boards) that can expand the basic capabilities of Arduino. Information about shields is available at http://shieldlist.org/.

Arduino hardware is programmed using a simplified C ++ language, in IDE-based processing. This software is then compiled and loaded on the chip. Arduino is also compatible with other software, including Flash, Processing, MaxMSP, and MATLAB. Some of the code needed in the operation of Arduino has been available open source in the form of modules in quite a lot and can see at http://arduino.cc/en/Reference/HomePage [3].

The basic programming structure of Arduino, C ++ language, consists of two parts namely the setup and loop components. The setup runs at the beginning and only once to set the pin mode or serial communication, these variables must declare first. The second part runs in a series of loops that allow scripts to change, respond to, and control the operation of Arduino [1].

The use of Arduino has also been developed to connect with mobile phones (iPhone). The application name is The Small Craft Motion Program (ScraMP) [7]. This application is intended to provide operators with low-costs and it was intended for fishers, so information about their ship movements can be monitored by utilizing the accelerometer and gyroscope from the Arduino and the location capabilities and a microprocessor from information about their ship movements can monitor.

2. METHOD

The research method uses a test approach so that the procedures that must be prepared are technical equipment for design or manufacture and analysis. The steps taken in data processing are 1) the selection stage of the measuring instrument module as needed, 2) the assembly and codding of measuring instruments, 3) validate the measuring instrument, 4) constructing the floating construction, 5) testing it with each load variation.

Figure 1 shows the placement scheme of the measuring instrument module using three ultrasonic sensors above the test model, and the IMU sensor is in the test model. Rotational motion measurement scheme as shown in Figure 2 is using the IMU sensor, while the translation measurement scheme shown in Figure 3 is using an ultrasonic sensor.

The devices in this study are Arduino Mega 2560 microcontroller, as a data processing device. Atmega 2560 core microcontroller board that has 50 input or output pins. The MPU-6050 module which produces output rolling and pitching values. It is an IMU module which contains an accelerometer and gyroscope device to estimate rotation motion (roll, pitch, yaw). The HC-SR04 module which produces heaving value output. An ultrasonic distance sensor that produces an output distance from objects is reflected by ultrasonic waves, the maximum range is 400-500 cm.

The first step is assembling a measuring instrument. Component connecting cables use extended jumper cables to adjust the placement of modules in towing tanks for measurement purposes. A series of connecting jumper cables is shown in Figure 4.

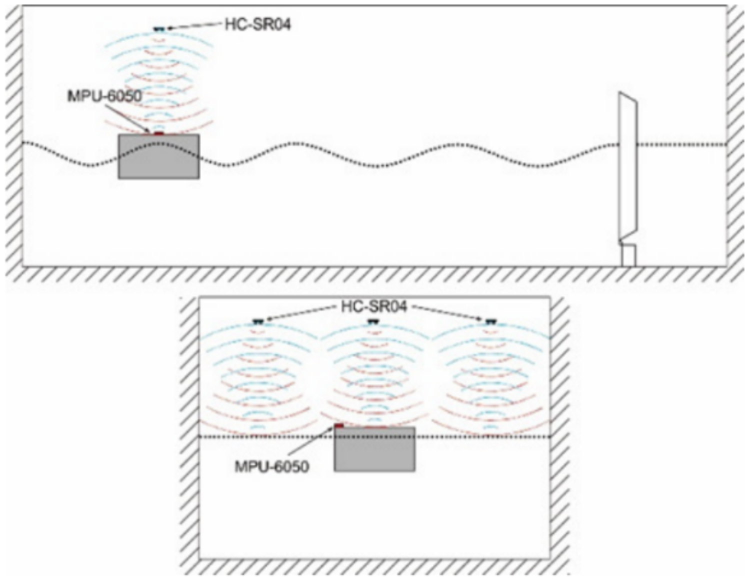

Figure 1 Measurement Module Placement Scheme

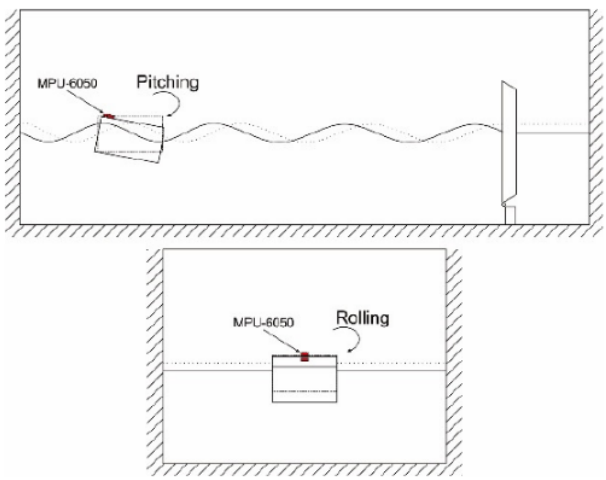

Figure 2 Scheme of Measurement of Rotation Movement

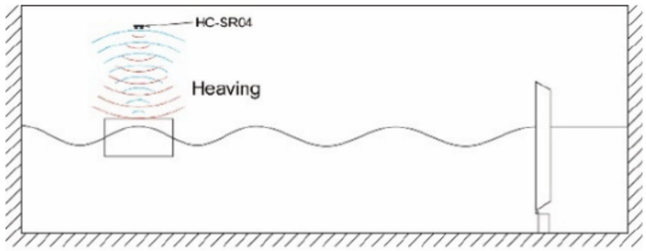

Figure 3 Measurement scheme for the translation movement.

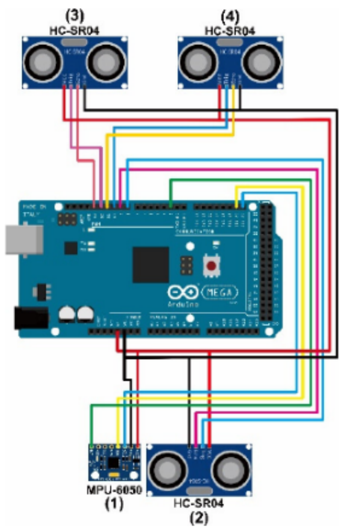

Figure 4 Measurement circuit.

As shown in Figure 4, number 1 is the IMU Sensor, MPU-6050. The Placement is on the floating structure to measure rotational movements [8]. Number 2 is Ultrasonic Sensor, HC-SR04 which is at the top of the floating structure to measure the translation/axial movements. Number 3 dan 4 are Ultrasonic Sensor, HC-SR04. The alignment is parallel across the floating structure to measure the regular wave height and the motion response of the floating structure. The placement of each device is shown in Figure 5

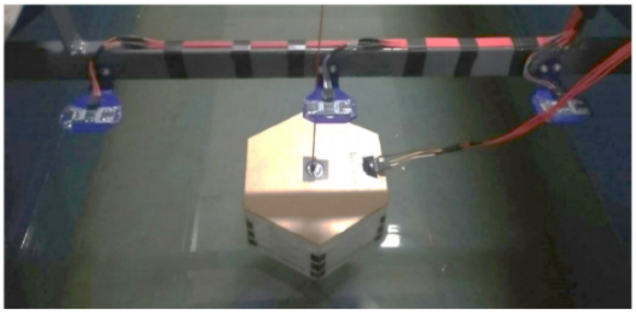

Figure 5 placement of the devices

The next step is constructing the floating structures which are a cylinder and prism hexagon with a diameter and a height of 10 cm as shown in Figure 6. The floating structures are described in Table 2. They are given a weight that varies according to the desired draft. Each draft is measured the motion response to the same wave.

A load of those floating structure is divided into a freshwater load and sand load for comparison purpose. Freshwater density is 1 g / cm^3 or equal to 1000 kg / m^3 and sand density is 1.55 g / cm^3 or equal to 1548 kg / m^3. Both of fresh water and sand are inserted into the pontoon as a load. There are 3 variations of the weight of the pontoon, as shown in Table 3. The measurement of motion response is carried out at different wave heights, which are 1.82 cm and 3.12 cm.

The measurement of motion response is carried out at different wave heights. The wave is generated from a wavemaker motor with 24V voltage (69 RPM) with a rotating radius of 40 mm and 80 mm. The wavemaker produces two wave variations, which are 1.82 cm and 3.12 cm. Figure 7 shows one of the two kinds of regular generated wave.

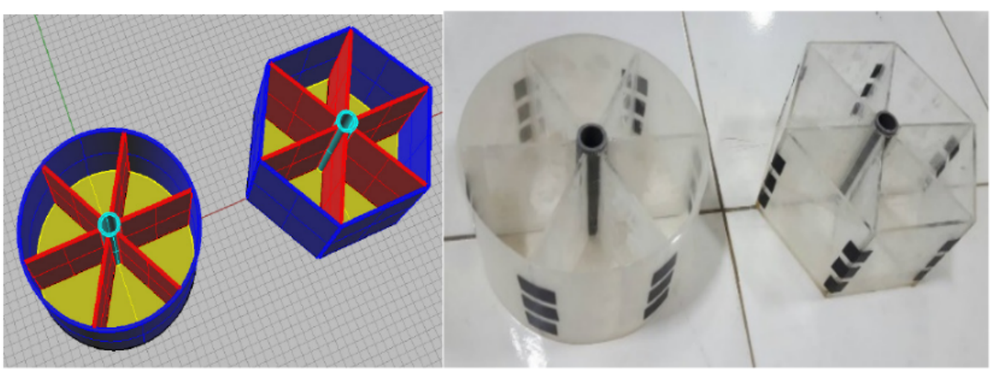

Figure 6 Floating Structure Model

Table 2 Description of Floating Structures

	Prism Hexagon	Cylinder
Cross-sectional area	25980 mm^2	25980 mm^2
Amount of Bulkhead.	6	6
High	100 mm	100 mm
Weight	480 gram	630 gram

Table 3 load variations on floating structures

No	Form	Load Type	Draft
1	Prism Hexagon	Sand	¼ H
2			½ H
3			¾ H
4		Fresh Water	¼ H
5			½ H
6			¾ H
7	Cylinder	Sand	¼ H
8			½ H
9			¾ H
10		Fresh Water	¼ H
11			½ H
12			¾ H

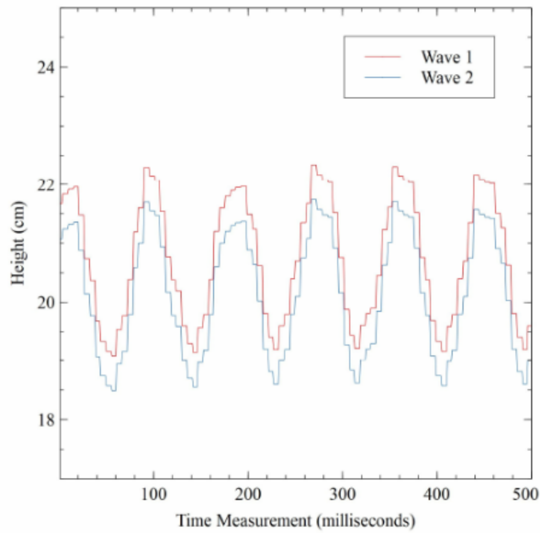

Figure 7 output chart of test wave measurements

3. RESULTS AND DISCUSSION

To validate the results from the MPU-6050 and HC-SR04, the protractor and the ruler are employed respectively. The MPU-6050 module measures the rotational motion with a degree values. Based on the measurement, the result is 19.97°. It equal to that shown in the protractor, which is around 19°- 20°. Module HC-SR04 measure translational motion. From the measurement, it shows that the results are 25 cm which is equal to that shown by the ruler.

Refer to Table 3. Taking samples on Prism Hexagon geometry, with the sand load as high as 1/2 H, with wave amplitude 2 (3.12 cm), the measurement results from 5 test show the difference in rolling value is insignificant (0.28 °). 4.11 ° as the highest value, and 3.83 ° as the lowest value. The highest value of pitching motion is 12.48 ° and 12.34 ° as the lowest value. The insignificant difference in pitching value is 0.14 °. Whereas the difference between the highest and lowest Heaving motion is 0.07 cm. the highest value is 2.58 cm and the lowest value is 2.51 cm.

The results of the module and microcontroller readings produce as many as 1000 outputs of each with values and movement patterns as shown in Figure 8. The test sample was carried out for 10 seconds.

Table 3 measurement results of prism hexagon geometry, with the sand load as high as 1/2 h, with wave amplitude 2 (3.12 cm).

Testing No	Roll Motion (°)	Pitch Motion (°)	Heaving Motion (cm)
1	4.11	12.34	2.58
2	4.05	12.43	2.52
3	4.06	12.48	2.56
4	3.93	12.48	2.51
5	3.83	12.47	2.52
Average	4.00	12.44	2.54

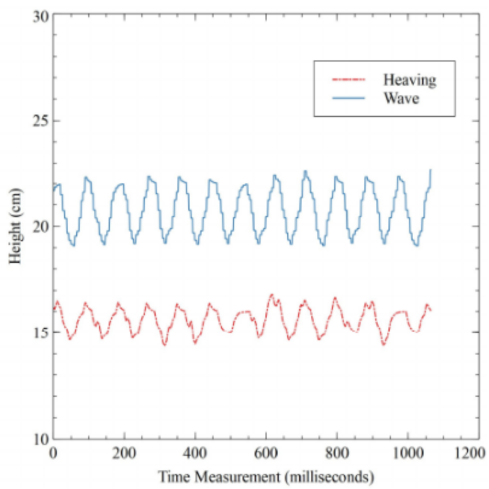

Figure 8 output chart of measuring instrument of prism hexagon geometry, with the sand load as high as 1/2 h, with wave amplitude 2 (3.12 cm)

Referring to Table 4, the largest rolling motion of both of type geometry occurs on sand load, 3.12 cm wave amplitude, and draft 1/2H. For draft ¼ H, the comparison of the rolling motion value based on the type of load variation is almost the same. When draft ½H, the rolling value of the sand load rises from the previous value, while the water load is relatively the same. On draft ¾ H experienced a significant difference, for the sand load decreased rolling value, and a load of water increased.

As shown in Table 5, the comparison of the pitch motion for the sand load experienced a non-significant difference in the variation of wave amplitude 1.82 cm and experienced a decrease in wave amplitude 3,12 cm. Whereas for the water load, there was a significant comparison on the draft ¾ H which increased pitch motion value.

Table 6 illustrates that the comparison variety of payloads for the heaving motion do not experience a significant difference. There is only one difference at prism hexagon when the draft ½ H for a sand load. the heaving motion rise although at 1/4H and 3/4H have a value that is almost the same.

Table 4 Roll Amplitude (°)

Form	Load	Wave Amplitude (cm)	Empty Load	Draft		
				¼ H	½ H	¾ H
Prism Hexagon	Sand	1.82	1.06	0.71	2.07	1.50
		3.12	2.35	2.14	4.00	2.28
	Water	1.82	1.06	0.71	0.83	2.18
		3.12	2.35	2.14	1.72	3.56
Cylinder	Sand	1.82	1.61	1.73	1.82	0.87
		3.12	2.15	3.69	4.25	1.21
	Water	1.82	1.61	1.51	1.80	2.54
		3.12	2.15	3.23	3.18	3.46

Table 5 Pitch Amplitude (°)

Form	Load	Wave Amplitude (cm)	Empty Load	Draft		
				¼ H	½ H	¾ H
Prism Hexagon	Sand	1.82	7.21	7.46	6.99	7.28
		3.12	12.63	13.46	12.44	9.89
	Water	1.82	7.21	7.46	7.29	10.93
		3.12	12.63	13.46	9.40	11.59
Cylinder	Sand	1.82	4.81	6.75	6.55	6.84
		3.12	10.19	11.26	10.27	10.25
	Water	1.82	4.81	7.86	8.11	9.87
		3.12	10.19	11.48	11.45	12.98

Table 6 Heave Amplitude (°)

Form	Load	Wave Amplitude (cm)	Empty Load	Draft		
				¼ H	½ H	¾ H
Prism Hexagon	Sand	1.82	1.13	0.98	1.50	1.02
		3.12	2.06	2.07	2.54	2.34
	Water	1.82	1.13	0.98	0.94	1.05
		3.12	2.06	2.07	2.42	2.52
Cylinder	Sand	1.82	1.20	1.05	1.14	1.18
		3.12	2.39	2.55	2.71	1.88
	Water	1.82	1.20	1.29	1.19	1.20
		3.12	2.39	2.25	2.39	1.92

4. CONCLUSION

The experimental results of differences in the measurement of motion values in floating structures with variations in the types of solid (sand) and liquid (water) can be concluded to have an amount that is not too different because there is enough bulkhead to block the movement of water in the floating structures.

The measuring instruments of floating structures motion response with the different type of load and wave height variations can be concluded that microcontroller-based motion measuring devices function quite well, with an output of 100 data per second from each value of the motion.

For the MPU-6050 module, the rotation motion detector has a very accurate output and a good result with a 0.01° correction. For HC-SR04 module the translation motion detection and wave height detector have an accurate enough output with 0.01 cm correction, but there is still a lot of noises that appear so it needs to use a filter to correct the output.

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