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Finally, we would like to express our sincere appreciation to all the authors and attendees for their contributions to ICoICT 2018

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# 2.4 GHz Wireless Data Acquisition System for FIToplankton ROV

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*Abstract*— **Research activity in underwater wireless sensor and video transmission for marine and aquatic environment monitoring has increased rapidly. Data acquisition system is essential component for Remotely Operated Vehicle (ROV) especially for marine or other aquatic environment surveillance. ROV's data acquisition is typically transmitted using tether cable connected to ground control station. The use of tether may cause a problem since the cable can hinder the movement of ROV especially for shallow water area. A mobile ROV with wireless data acquisition solution play a key role in underwater environment monitoring. This paper presented an alternative method of data acquisition using 2.4 GHz Wi-Fi communication module on existing ROV platform of Telkom University - FIToplankton. This study aims to explore the possibility of Wi-Fi communication device as underwater IMU sensor's data and video transmission system. The prototype of the system has been implemented and evaluated to confirm the functionality of the proposed approach. The results indicate sensor and video data can still transmitted up to 20 cm water depth.**

***Keywords—data acquisition; ROV; wireless; communication; sensor; video;Wi-Fi***

## I. INTRODUCTION

Research activity in underwater wireless sensor and video transmission for marine and aquatic environment monitoring has increased rapidly. Recent studies have shown that data acquisition system is essential component for Remotely Operated Vehicle (ROV) especially for underwater environment monitoring research. ROV's data acquisition is typically transmitted using tether cable connected to surface control station. The use of tether may cause a problem since the cable can hinder the movement of ROV especially for shallow water area [1]. A mobile ROV with wireless data acquisition solution should play a key role as an alternative method in underwater environment monitoring. However, underwater wireless communication still faces a challenge, particularly when the high bandwidth demand is required as well as low latency, like real-time video streaming [2].

Conventional underwater wireless communication modules have used acoustic waves for data transmission. Although the waves could travel over several kilometers, acoustic communications have several disadvantages i.e. the considerable propagation delay of sound waves in contrast to electromagnetic (EM) waves [2] and low data rate (0-20 kbps) [3].

Previous work has suggested the deployment of numerous static remote sensing buoys at specific location for detecting underwater parameters on coastal area [4]. A combination between wireless and wired solution for marine environment surveillance also have been suggested overcome wireless communication limitation [4][5]. This method is proposed involving four main subsystems: marine buoy, wireless action camera, a control unit for capturing a still image, and communication unit for data transmission. Meanwhile, another alternative methods for underwater monitoring are already proposed by researchers, such as Underwater Wireless Sensor Network (UWSN) [6], underwater wireless optical communication system [7], and ZigBee wireless network [8].

The aim of this study was to observe a possibility of underwater data acquisition using 2.4 GHz Wi-Fi communication. Particularly, the contribution of this paper is the development of wireless data acquisition system on ROV platform for IMU sensor data and video. This study was performed using FIToplankton, small ROV that developed by Robotic – SAS team from Telkom University.

The rest of this paper is organized as follows. Section II describes a literature review from related works conducted by several researchers. The development of system is presented in section III. Section III also describes the methodology of data acquisition. Section IV describes result and discussion from the experiments. Finally, section V shows the final remarks of conclusion.

## II. RELATED WORKS

Much effort has been devoted by several researchers develop a methods for increasing the distance between devices and increasing the bandwidth in underwater video and data streaming. Wireless camera for capturing image or recording video has been used for short distance [8]. A 2.4 GHz RF transceiver module can be used to transmit and receive data at multiple baud rates from any standard CMOS/TTL source. But first, to allow video transmission, the maximum distance between nodes and the round trip time (RTT) must be

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calculated first. Recently, the study on behavior of EM waves at 2.4 GHz in freshwater underwater environments presents intriguing results. Results indicate that the value is depending on data transfer rate, signal modulations, frequency, and water temperature [9]. Another study has demonstrated that subsea RF communication system can provide data rates of up to 10 Mbps at very close ranges (1-2 m) [10].

Although the RF communications with underwater vehicles have a very limited usage due to the high attenuation of RF waves through water, it's still possible using electromagnetic energy transmission capability through shallow water [11]. Radio wave propagation has different properties on fresh water and sea water [12]. Lower frequency between 30-300 Hz is usually used for underwater RF communication [13]. From this information, we can conclude that there is a possibility for using wireless data communication for ROV for underwater environment monitoring.

## III. System Design

### A. Hardware Development

The first phase for developing the hardware is by modifying ROV structure, sensors and related communication device for data acquisition system. Underwater camera is attached to ROV. FIToplankton ROV platform is shown in Fig. 1. Fig. 2 shows the system block diagram. It contains two main subsystems: first, ROV platform with underwater wireless communication module for data streaming and PC-based ground control station software for receiving and processing an incoming data from ROV.

WaveShare 10-DOF Inertial Measurement Unit (IMU) is used as a motion sensor. This sensor is consisted of MPU9255 (3-axis gyroscope, 3-axis accelerometer, and 3-axis magnetometer) and BMP180 (barometric pressure sensor). Accelerometer is used for measuring ROV's acceleration. Meanwhile, gyroscope is used for measuring ROV's position orientation and accelerometer correction purpose. Magnetometer is used as digital compass for direction/heading.

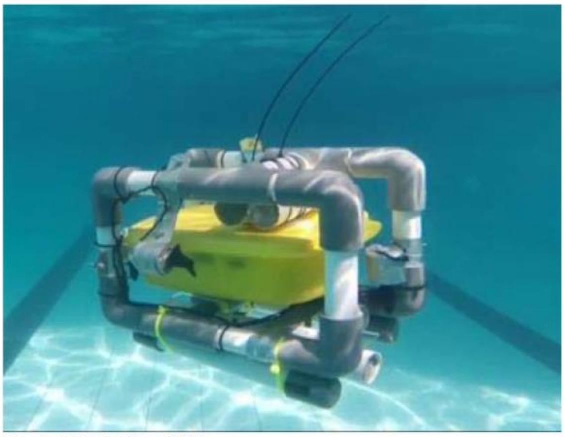


Fig. 1. FIToplankton ROV

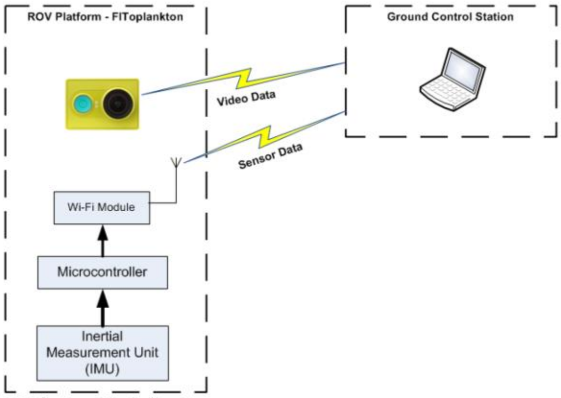



Fig. 2. System block diagram.

The specification of camera that used in this system is shown in TABLE I. The Xiaomi Yi wireless action camera is used with WLAN 802.11 b/g/n capability. The camera's video setting is set on 720p with 60 frame per second.

TABLE I. Underwater Camera Specification

| Part Name | Specification |
|---|---|
| Image Processor | Ambarella A7LS high-performance processor |
| Image Sensor | 16MP Sony EXMOR R CMOS BSI image sensor |
| Lens | 155° ultra wide angle glass lens / F2.8 Aperture |
| G Sensor | ST high performance g-sensor |
| Waterproof: | Waterproof up to 40 m deep with waterproof housing (sold separately) |
| Video Compression Format | High-definition H.264 image encoding |
| Video Format | MP4 |
| Video | 1080p@60fps, 48fps, 30fps, 24fps<br>960p@48fps<br>720p@120fps, 60fps, 48fps<br>480p@240fps |
| WLAN | Wi-Fi 802.11 b/g/n, Wi-Fi Direct, hotspot |

The each sensor on IMU has three MEMS component for detecting rotational movement of each in the X-axis (roll), Y axis (pitch), and Z-axis (yaw). When the sensor is rotated, *coriolis effect* will cause deflection which will be read by the capacitive components in the sensor[14]. A capacitance change in the components is then amplified, demodulated, and filtered to produce a voltage whose value is proportional to the angular rate. This voltage is then converted into digital form using the Analog-to-Digital Converter (ADC) in each axis. ata from these registers must be reconstructed prior to the 16-bit data format (2 bytes). Detail specification of 10 DoF (Degree of Freedom) IMU is shown in TABLE II [15].

TABLE II. 10 DOF IMU SPECIFICATION

| Part Name | Specification |
|---|---|
| MPU9255(3-axis accelerometer, 3-axis gyroscope, 3-axis digital compass) | Built-in 16-Bit AD convertor<br>Gyroscope full-scope range: ±250, ±500, ±1000, ±2000°/sec<br>Accelerometer full-scale range: ±2, ±4, ±8, ±16g<br>Compass full-scale rage : ±4800uT |
| BMP180 (barometric pressure sensor) | Built-in temperature sensor with temperature measurement compensation<br>Pressure measuring range: 300~1100hpa (+9000m ~ -500m relating to sea level)<br>Accuracy: 0.02hPa (0.17m) |

### B. Software Development

The system is divided into three parts: a software for ground control station, Wi-Fi connected action camera, and IMU sensor's data transmitter. To reduce the computing requirements on the sensor node, raw sensor data in transmitted. The sensor data transmitter managed the output from sensor data into a data package and sent it to Wi-Fi module which will sent it to the receiver. Flowchart of data acquisition system process is shown in Fig. 3.

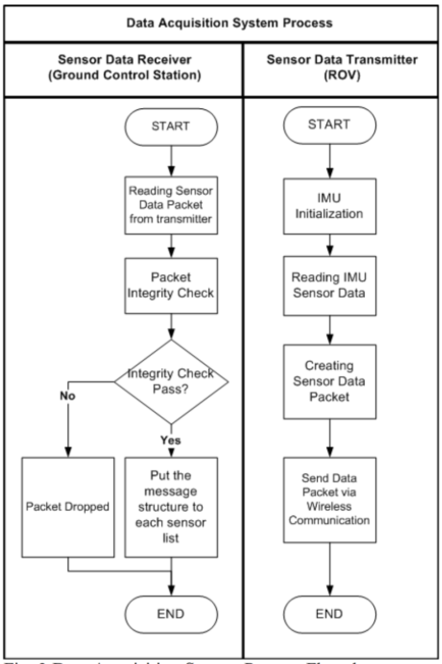


Fig. 3 Data Acquisition System Process Flowchart

Each packet is added with timestamp each time it's transmitted (Fig. 4). Every data package contains 35 byte, Node ID (1 byte), index (2 byte), accelerometer data (2 byte per axis, total 6 byte), gyroscope (2 byte per axis, total 6 byte), barometric pressure (2 byte), temperature sensor (1 byte) and end packet flag (6 byte) for marking the end of packet.

| Node ID | Index /Time stamp | Accel. (x,y,z) | Gyro (x,y,z) | Magnet. (x,y,z) | Barometric Pressure | Temp. | End Packet Flag |
|---|---|---|---|---|---|---|---|
| 1 Byte | 2 Byte | 6 byte | 6 byte | 6 byte | 4 byte | 4 byte | 6 byte |

Fig. 4 Sensor Data Package.

The main purpose is to log all the sensors output in real time and if the CPU still have idle power it can be used to simultaneously processing displaying the data. To achieve that, the software using 3 threads :

1. Receiving and reading raw sensor data
2. Processing raw data from the sensors.
3. Displaying the processed data in real-time.

The first thread works by continuously monitoring the connection from ROV to receiver and receiving the data packet. When a packet arrives, the packet integrity is checked first. After that, the packet was dismantled and the contents are put into a sensor message structure and timestamp is added. Then this structure is added to the list of the structure of the same sensor node, which each sensor has its own list. Node identifier (Node ID) is used to determine if the data came from same sensor. This scheme is planned to use for multi ROV monitoring in future works.
After the data acquisition process, the second thread will process the raw data from the sensor. MPU9255 data reconstruction process requires 16 bits (2 bytes) data format. This raw data must be converted into useful information by applying correction scale or gravitational acceleration G (1 G = 9.8 m/s$^2$) with a resolution of 10 bits. Settings that provided are 2G, 4G, 8G and 16G. The higher the setting is selected, the noise is also greater. 2G setting is chosen due to ROV doesn't require high acceleration. Meanwhile, the third thread is optional, and used for displaying the data in line chart form in future works.

## IV. RESULTS AND ANALYSIS

### A. Wireless Communication Experiment Result

After implementation, system is tested on 1.5 meter depth swimming pool. This test is conducted to evaluate wireless communication module ability i.e. signal penetration on water. This result is depend on value of water conductivity is known, it can be used to calculate the values of the signal's penetration depth. The penetration depth δ (in centimeter) can be calculated using the following formula [11]:

$$\delta = \frac{1}{\sqrt{\pi f \mu \sigma}} \quad (1)$$

Where $f$ is frequency of the electromagnetic wave, $\mu$ is absolute magnetic permeability of the conductor, $\sigma$ is water conductivity and $\mu$ is water's magnetic permeability that assumed same as the vacuum magnetic permeability ($\mu_0$ = $4\pi x10^{-7}$ H/m). The water conductivity is assumed constant. Fresh water conductivity typically varies between from 30 µS/cm - 2000 µS/cm [11][16]. The penetration depth value will be calculated both for the best (30 µS/cm) and the worst (2000 µS/cm) case. In this case, at the frequency of 2.4 GHz Wi-Fi module. The value of penetration depth at 2.4 GHz can be calculated using (1) with a conductivity value respectively of 30 µS/cm (3 mS/m) and 2000 µS/cm (0.2 S/m). The results are shown on (2) and (3).

$$\delta_{2.4\ \text{GHz}} = \frac{1}{\sqrt{\pi \cdot 2.4 \cdot 10^9 \cdot 4\pi \cdot 10^{-7} \cdot 3 \cdot 10^{-3}}} \approx 18.76 \text{ cm} \qquad (2)$$

$$\delta_{2.4\ \text{GHz}} = \frac{1}{\sqrt{\pi \cdot 2.4 \cdot 10^9 \cdot 4\pi \cdot 10^{-7} \cdot 0.2}} \approx 2.3 \text{ cm} \qquad (3)$$

From this information, it can be concluded that the Wi-Fi signal's penetration depth depends on the frequency. Higher frequency leads to lower signal's penetration depth. This result indicates that wireless communication using 2.4 GHz Wi-Fi can be used for data acquisition on very shallow water (< 20 cm).

### *B. Sensor Receiver Software Ground Test Result*

Several test scenarios have been conducted to evaluate transmitter and receiver capability. First scenario (Fig. 5) involves ground testing for the system. The goal is to evaluate wireless transmission capability from 0 to 8 meters. Video configuration is set on 720p and 60 fps.

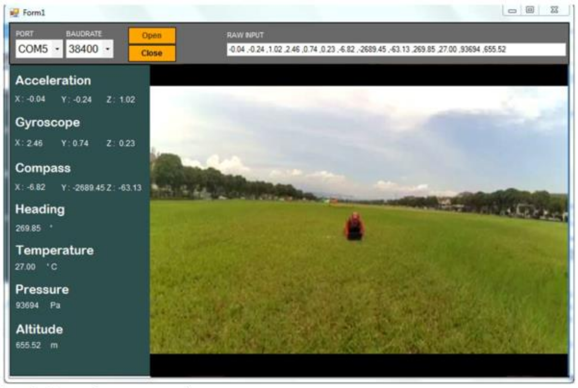



Fig. 5 Ground test scenario.

Evidence used to establish benchmark between ground and water test have so far been obtained from TABLE III. Our data suggest that packet loss is occurred in 8 meters range, with no significant delay.

TABLE III. GROUND TEST RESULTS.

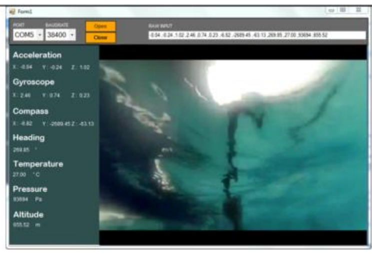
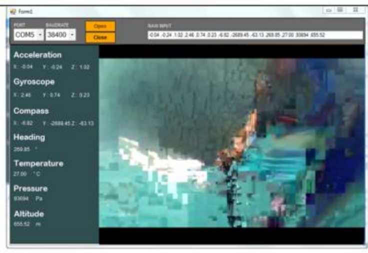
| No | Range (m) | Throughput (Mbit/sec) | Delay (s) | Jitter (ms) | Packet Loss (%) |
|---|---|---|---|---|---|
| 1. | 2 | 0.43479 | 0.014 | 0.00 | 0.00 |
| 2. | 4 | 0.42871 | 0.015 | 0.00 | 0.00 |
| 3. | 6 | 0.43012 | 0.015 | 0.00 | 0.00 |
| 4. | 8 | 0.42395 | 0.015 | 0.00 | 0.67 |

### *C. Sensor Receiver Software Water Test Result*

Aside from the water attenuation problem, the data is very reliable on water test. The main problem is from four parameter that calculated, two of those rely heavily on magnetometer. Heading and compass data can't be used reliably since there's too much noise in the sensor because magnetic disturbance from ROV's motor. For temporary fix, an offset input is added.

TABLE IV is the result of capturing video streaming from under water with various depth. Referring to the ITU-T G.1010 standard for Quality of Service (QoS) [17], these results provide visual evidence for video streaming quality transmission from underwater to receiver.

TABLE IV. SOFWARE TEST RESULTS.

| Results | Depth (cm) |
|---|---|
|  | 5 |
|  | 10 |
|  | 15 |
|  | 20 |

These qualitative results explain QoS variation between 5 and 20 cm. At a depth of 5 cm, video streaming quality is still excellent because the delay is only 0.015s and its packet loss is only 0.55% resulting in real-time video streaming. At a depth of 10 cm, video streaming still run without significant delay on 0.024s delay and packet loss of 6.25% resulting in less intact images and slightly disjointed video movement. At a depth of 15 cm, video streaming can still run with 0.033s delay and packet loss of 20.33% resulting in less clear and incomplete images as well as intermittent video movement. At a depth of 20 cm, the streaming video started to stop with 60s delay and packet loss of 52.71%. The receiver only displayed gray-dominated image. This result indicates (TABLE V) that the deeper water, the packet loss and delay will be greater. This result reflects the following basic phenomenon as discussed before: radio wave attenuation on water.

TABLE V. WATER TEST RESULTS.

| No. | Range (cm) | Throughput (Mbit/sec) | Delay (s) | Jitter (ms) | Packet Loss (%) |
|---|---|---|---|---|---|
| 1. | 5 | 0.4274 | 0.015 | 0 | 0.55 |
| 2. | 10 | 0.2648 | 0.024 | 0 | 6.25 |
| 3. | 15 | 0.1828 | 0.033 | 0 | 20.33 |
| 4. | 20 | 0.0707 | 60 | 0 | 52.71 |

## V. CONCLUSIONS

The findings of our study suggest that an alternative method for developing wireless data acquisition can be done within several conditions. Firstly, it is possible to use 2.4 GHz for transmitting sensor data for underwater applications on very shallow water (< 20 cm depth). This method can be used for underwater monitoring by combining the advantage of electromagnetic and acoustic communications [18]. These important results indicate that there are considerably higher losses corresponding to water depth. Future works on this field should be directed at different water condition scenario and with different radio frequency. The lower frequency between 10 KHz to 1 MHz could be beneficial for further research on the field for different water depth [19]. Meanwhile, previous work has demonstrated that ISM 433 MHz RF transceiver module can be utilized for ROV's controlling on shallow water [20]. This research could be expanded to include a floating platform as an intermediary between underwater network and surface communication [18][21][22].

Secondly, the video streaming using wireless only works in excellent condition at a depth of 5-10 cm. At a depth of more than 10 cm, the video quality dropped. Further considerations also include the use of floating platform with Wi-Fi range extender to extend wireless video signal from underwater camera to the surface without considerable losses [4].

## ACKNOWLEDGMENT

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# 2.4 GHz Wireless Data Acquisition System for FIToplankton ROV

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# 2.4 GHz Wireless Data Acquisition System for FIToplankton ROV

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***Abstract*— Research activity in underwater wireless sensor and video transmission for marine and aquatic environment monitoring has increased rapidly. Data acquisition system is essential component for Remotely Operated Vehicle (ROV) especially for marine or other aquatic environment surveillance. ROV's data acquisition is typically transmitted using tether cable connected to ground control station. The use of tether may cause a problem since the cable can hinder the movement of ROV especially for shallow water area. A mobile ROV with wireless data acquisition solution play a key role in underwater environment monitoring. This paper presented an alternative method of data acquisition using 2.4 GHz Wi-Fi communication module on existing ROV platform of Telkom University - FIToplankton. This study aims to explore the possibility of Wi-Fi communication device as underwater IMU sensor's data and video transmission system. The prototype of the system has been implemented and evaluated to confirm the functionality of the proposed approach. The results indicate sensor and video data can still transmitted up to 20 cm water depth.**

***Keywords—data acquisition; ROV; wireless; communication; sensor; video;Wi-Fi***

## I. Introduction

Research activity in underwater wireless sensor and video transmission for marine and aquatic environment monitoring has increased rapidly. Recent studies have shown that data acquisition system is essential component for Remotely Operated Vehicle (ROV) especially for underwater environment monitoring research. ROV's data acquisition is typically transmitted using tether cable connected to surface control station. The use of tether may cause a problem since the cable can hinder the movement of ROV especially for shallow water area [1]. A mobile ROV with wireless data acquisition solution should play a key role as an alternative method in underwater environment monitoring. However, underwater wireless communication still faces a challenge particularly when the high bandwidth demand is required as well as low latency, like real-time video streaming [2].

Conventional underwater wireless communication modules have used acoustic waves for data transmission. Although the waves could travel over several kilometers, acoustic communications have several disadvantages i.e. the considerable propagation delay of sound waves in contrast to electromagnetic (EM) waves [2] and low data rate (0-20 kbps) [3].

Previous work has suggested the deployment of numerous static remote sensing buoys at specific location for detecting underwater parameters on coastal area [4]. A combination between wireless and wired solution for marine environment surveillance have been suggested overcome wireless communication limitation [4][5]. This method is proposed involving four main subsystems: marine buoy, wireless action camera, a control unit for capturing a still image, and communication unit for data transmission. Meanwhile, another alternative methods for underwater monitoring are already proposed by researchers, such as Underwater Wireless Sensor Network (UWSN) [6], underwater wireless optical communication system [7], and ZigBee wireless network [8].

The aim of this study was to observe a possibility of underwater data acquisition using 2.4 GHz Wi-Fi communication. Particularly, the contribution of this paper is the development of wireless data acquisition system on ROV platform for IMU sensor data and video. This study was performed using FIToplankton, small ROV that developed by Robotic – SAS team from Telkom University.

The rest of this paper is organized as follows. Section II describes a literature review from related works conducted by several researchers. The development of system is presented in section III. Section III also describes the methodology of data acquisition. Section IV describes result and discussion from the experiments. Finally, section V shows the final remarks of conclusion.

## II. Related Works

Much effort has been devoted by several researchers develop a methods for increasing the distance between devices and increasing the bandwidth in underwater video and data streaming. Wireless camera for capturing image or recording video has been used for short distance (300 feet) [8]. An 2.4 GHz RF transceiver module can be used to transmit and receive data at multiple baud rates from any standard CMOS/TTL source. But first, to allow video transmission, the maximum distance between nodes and the round trip time

(RTT) must be calculated first. Recently, the study on behavior of EM waves at 2.4 GHz in freshwater underwater environments presents intriguing results. Results indicate that the value is depending on data transfer rate, signal modulations, frequency, and water temperature [9]. Another study has demonstrated that subsea RF communication system can provide data rates of up to 10 Mbps at very close ranges (1-2 m) [10].

Although the RF communications with underwater vehicles have a very limited usage due to the high attenuation of RF waves through water, it's still possible using electromagnetic energy transmission capability through shallow water [11]. Radio wave propagation has different properties on fresh water and sea water [12]. Lower frequency between 30-300 Hz is usually used for underwater RF communication [13]. From this information, we can conclude that there is a possibility for using wireless data communication for ROV for underwater environment monitoring.

## III. System Design

### A. Hardware Development

The first phase for developing the hardware is by modifying ROV structure, sensors and related communication device for data acquisition system. Underwater camera is attached to ROV. FIToplankton ROV platform is shown in Fig. 1. Fig. 2 shows the system block diagram. It contains two main subsystems: first, ROV platform with underwater wireless communication module for data streaming and PC-based ground control station software for receiving and processing an incoming data from ROV.

The sensors used are WaveShare 10-DOF Inertial Measurement Unit (IMU) that consist of MPU9255 (3-axis gyroscope, 3-axis accelerometer, and 3-axis magnetometer) and BMP180 (barometric pressure sensor). Accelerometer is used for measuring ROV's acceleration. Meanwhile, gyroscope is used for measuring ROV's position orientation and accelerometer correction purpose. Magnetometer is used as digital compass for direction/heading.

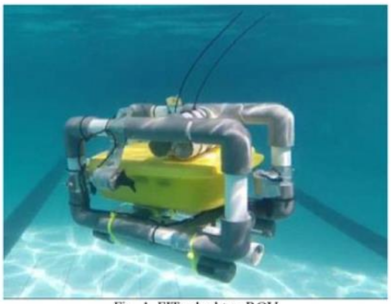


Fig. 1. FIToplankton ROV

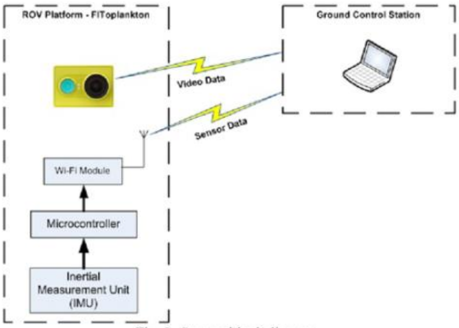



Fig. 2. System block diagram.

The specification of camera that used in this system is shown in TABLE I. The Xiaomi Yi wireless action camera is used with WLAN 802.11 b/g/n capability. The camera's video setting is set on 720p with 60 frame per second.

TABLE I UNDERWATER CAMERA SPECIFICATION

| Part Name | Specification |
|---|---|
| Image Processor | Ambarella A7LS high-performance processor |
| Image Sensor | 16MP Sony EXMOR R CMOS BSI image sensor |
| Lens | 155° ultra wide angle glass lens / F2.8 Aperture |
| G Sensor | ST high performance g-sensor |
| Waterproof: | Waterproof up to 40 m deep with waterproof housing (sold separately) |
| Video Compression Format | High-definition H.264 image encoding |
| Video Format | MP4 |
| Video | 1080p@60fps, 48fps, 30fps, 24fps<br>960p@48fps<br>720p@120fps, 60fps, 48fps<br>480p@240fps |
| WLAN | Wi-Fi 802.11 b/g/n, Wi-Fi Direct, hotspot |

The each sensor on IMU has three MEMS component for detecting rotational movement of each in the X-axis (roll), Y axis (pitch), and Z-axis (yaw). When the sensor is rotated, *coriolis effect* will cause deflection which will be read by the capacitive components in the sensor[14]. A capacitance change in the components is then amplified, demodulated, and filtered to produce a voltage whose value is proportional to the angular rate. This voltage is then converted into digital form using the Analog-to-Digital Converter (ADC) in each axis. ata from these registers must be reconstructed prior to the 16-bit data format (2 bytes). Detail specification of 10 DoF (Degree of Freedom) IMU is shown in TABLE II [15].

TABLE II 10 DOF IMU SPECIFICATION

| Part Name | Specification |
|---|---|
| MPU9255(3-axis accelerometer, 3-axis gyroscope, 3-axis digital compass) | Built-in 16-Bit AD convertor<br>Gyroscope full-scope range: ±250, ±500, ±1000, ±2000°/sec<br>Accelerometer full-scale range: ±2, ±4, ±8, ±16g<br>Compass full-scale rage : ±4800uT |
| BMP180 (barometric pressure sensor) | Built-in temperature sensor with temperature measurement compensation<br>Pressure measuring range: 300~1100hpa (+9000m ~ -500m relating to sea level)<br>Accuracy: 0.02hPa (0.17m) |

*B. Software Development*

The system is divided into three parts: a software for ground control station, Wi-Fi connected action camera, and IMU sensor's data transmitter. To reduce the computing requirements on the sensor node, raw sensor data in transmitted. The sensor data transmitter managed the output from sensor data into a data package and sent it to Wi-Fi module which will sent it to the receiver. Flowchart of data acquisition system process is shown in Fig. 3.

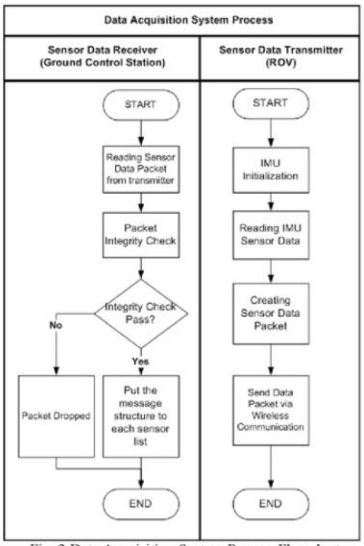


Fig. 3 Data Acquisition System Process Flowchart

Each packet is added with timestamp each time it's transmitted ( Fig. 4 ). Every data package contains 35 byte, Node ID (1 byte), index (2 byte), accelerometer data (2 byte per axis, total 6 byte), gyroscope (2 byte per axis, total 6 byte), barometric pressure (2 byte), temperature sensor (1 byte) and end packet flag (6 byte) for marking the end of packet.

| Node ID | Index /Timestamp | [illegible] (x,y,z) | Gyro (x,y,z) | Magnet. (x,y,z) | Barometric Pressure | Temp. | End Packet Flag |
|---|---|---|---|---|---|---|---|
| 1 Byte | 2 Byte | 6 byte | 6 byte | 6 byte | 4 byte | 4 byte | 6 byte |

Fig. 4 Sensor Data Package.

The main purpose is to log all the sensors output in real time and if the CPU still have idle power it can be used to simultaneously processing displaying the data. To achieve that, the software using 3 thread :

1. Receiving and reading raw sensor data
2. Processing raw data from the sensors.
3. Displaying the processed data in real-time.

The first thread works by continuously monitoring the connection from ROV to receiver and receiving the data packet. When a packet arrives, the packet integrity is checked first. After that, the packet was dismantled and the contents are put into a sensor message structure and timestamp is added. Then this structure is added to the list of the structure of the same sensor node, which each sensor has its own list. Node identifier (Node ID) is used to determine if the data came from same sensor. This scheme is planned to use for multi ROV monitoring in future works.

After the data acquisition process, the second thread will process the raw data from the sensor. MPU9255 data reconstruction process requires 16 bits (2 bytes) data format. This raw data must be converted into useful information by applying correction scale or gravitational acceleration G (1 G = 9.8 m/s$^2$) with a resolution of 10 bits. Settings that provided are 2G, 4G, 8G and 16G. The higher the setting is selected, the noise is also greater. 2G setting is chosen due to ROV doesn't require high acceleration. Meanwhile, the third thread is optional, and used for displaying the data in line chart form in future works.

## IV. RESULTS AND ANALYSIS

*A. Wireless Communication Experiment Result*

After implementation, system is tested on 1.5 meter swimming pool. This test is conducted to evaluate its ability i.e. signal penetration on water. This result is depend on value of water conductivity is known, it can be used to calculate the values of the signal's penetration depth. The penetration depth δ (in centimeter) can be calculated using the following formula [11]:

$$\delta = \frac{1}{\sqrt{\pi f \mu \sigma}} \tag{1}$$

Where $f$ is frequency of the electromagnetic wave, $\mu$ is absolute magnetic permeability of the conductor, $\sigma$ is water conductivity and $\mu$ is water's magnetic permeability that assumed same as the vacuum magnetic permeability ($\mu_0$ = $4\pi x10^{-7}$ H/m). The water conductivity is assumed constant. Fresh water conductivity typically varies between from 30 μS/cm - 2000 μS/cm [11] [16]. The penetration depth value will be calculated both for the best (30 μS/cm) and the worst (2000 μS/cm) case. In this case, at the frequency of 2.4 GHz Wi-Fi module. The value of penetration depth at 2.4 GHz can be calculated using equation (1) with a conductivity value respectively of 30 μS/cm (3 mS/m) and 2000 μS/cm (0.2 S/m). The results are shown on equation (2) and (3).

$$\delta_{2.4\ \text{GHz}} = \frac{1}{\sqrt{\pi \cdot 2.4 \cdot 10^{9} \cdot 4\pi \cdot 10^{-7} \cdot 3 \cdot 10^{-3}}} \approx 18.76\ \text{cm} \quad (2)$$

$$\delta_{2.4\ \text{GHz}} = \frac{1}{\sqrt{\pi \cdot 2.4 \cdot 10^{9} \cdot 4\pi \cdot 10^{-7} \cdot 0.2}} \approx 2.3\ \text{cm} \quad (3)$$

From this information, it can be concluded that the Wi-Fi signal's penetration depth depends on the frequency. The higher the frequency, the lower the signal's penetration depth. This result indicates that wireless communication using 2.4 GHz Wi-Fi can be used for data acquisition on very shallow water (< 20 cm).

### B. Sensor Receiver Software Ground Test Result

Several test scenario have been conducted to evaluate transmitter and receiver capability. First scenario (Fig. 5) involves ground testing for the system. The goal is to evaluate wireless transmission capability between 0 - 8 meters. Video configuration is set on 720p and 60 fps.

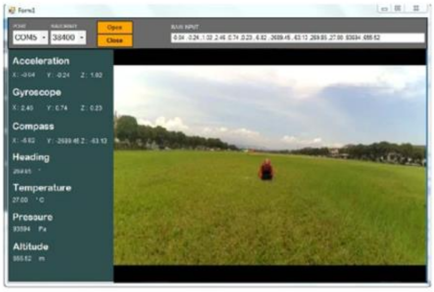



Fig. 5 Ground test scenario.

Evidence used to establish benchmark between ground and water test have so far been obtained from TABLE III. Our data suggest that packet loss is occurred in 8 meters range, with no significant delay.

TABLE III GROUND TEST RESULTS.

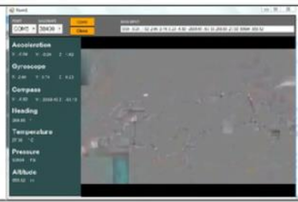
| No | Range (m) | Throughput (Mbit/sec) | Delay (s) | Jitter (ms) | Packet Loss (%) |
|---|---|---|---|---|---|
| 1. | 2 | 0.43479 | 0.014 | 0.00 | 0.00 |
| 2. | 4 | 0.42871 | 0.015 | 0.00 | 0.00 |
| 3. | 6 | 0.43012 | 0.015 | 0.00 | 0.00 |
| 4. | 8 | 0.42395 | 0.015 | 0.00 | 0.67 |

### C. Sensor Receiver Software Water Test Result

Aside from the water attenuation problem, the data is very reliable on water test. The main problem is from four parameter that calculated, two of those rely heavily on magnetometer. Heading and compass data can't be used reliably since there's too much noise in the sensor because magnetic disturbance from ROV's motor. For temporary fix, an offset input is added.

TABLE IV is the result of capturing video streaming from under water with various depth. Referring to the ITU-T G.1010 standard for Quality of Service (QoS) [17], these results provide visual evidence for video streaming quality transmission from underwater to receiver.

TABLE IV SOFWARE TEST RESULTS.

| Results | Depth (cm) |
|---|---|
|  | 5 |
|  | 10 |
|  | 15 |
|  | 20 |

These qualitative results explain QoS variation between 5-20 cm. At a depth of 5 cm, video streaming quality is still excellent because the delay is only 0.015s and its packet loss is only 0.55% resulting in real-time video streaming. At a depth of 10 cm, video streaming still run without significant delay on 0.024s delay and packet loss of 6.25% resulting in less intact images and slightly disjointed video movement. At a depth of 15 cm, video streaming can still run with 0.033s delay and packet loss of 20.33% resulting in less clear and incomplete images as well as intermittent video movement. At a depth of 20 cm, the streaming video started to stop with 60s delay and packet loss of 52.71%. The receiver only displayed gray-dominated image. This result indicates (TABLE V) that the deeper water, the packet loss and delay will be greater. This result reflects the following basic phenomenon as discussed before: radio wave attenuation on water.

TABLE V WATER TEST RESULTS.

| No. | Range (cm) | Throughput (Mbit/sec) | Delay (s) | Jitter (ms) | Packet Loss (%) |
|---|---|---|---|---|---|
| 1. | 5 | 0.4274 | 0.015 | 0 | 0.55 |
| 2. | 10 | 0.2648 | 0.024 | 0 | 6.25 |
| 3. | 15 | 0.1828 | 0.033 | 0 | 20.33 |
| 4. | 20 | 0.0707 | 60 | 0 | 52.71 |

## V. CONCLUSIONS

The findings of our study suggest that an alternative method for developing wireless data acquisition can be done within several conditions. Firstly, it is possible to use 2.4 GHz for transmitting sensor data for underwater applications on very shallow water (< 20 cm depth). This method can be used for underwater monitoring by combining the advantage of electromagnetic and acoustic communications [18]. These important results indicate that there are considerably higher losses corresponding to water depth. Future works on this field should be directed at different water condition scenario and with different radio frequency. The lower frequency between 10 KHz to 1 MHz could be beneficial for further research on the field for different water depth [19]. Meanwhile, previous work has demonstrated that ISM 433 MHz RF transceiver module can be utilized for ROV's controlling on shallow water [20]. This research could be expanded to include a floating platform i.e. buoy as an intermediary between underwater network and surface communication [18][21][22].

Secondly, the video streaming using wireless only works in excellent condition at a depth of 5-10 cm. At a depth of more than 10 cm, the video quality dropped. Further considerations also include the use of floating platform with Wi-Fi range extender to extend wireless video signal from underwater camera to the surface without considerable losses [4].

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