TELKOMNIKA, Vol.17, No.2, April 2019, pp.593~600
ISSN: 1693-6930, accredited First Grade by Kemenristekdikti, Decree No: 21/E/KPT/2018
DOI: 10.12928/TELKOMNIKA.v17i2.11791

Low-cost communication system for explorer-class underwater remotely operated vehicle

Simon Siregar*, Muhammad Ikhsan Sani, Muhammad Muchlis Kurnia, Dzikri Hasbialloh
Computer Engineering Department, Faculty of Applied Science, Telkom University,
Telekomunikasi St. Terusan Buah Batu, Bandung, Indonesia
*Corresponding author, e-mail: simon.siregar@tass.telkomuniversity.ac.id

Abstract

Disaster recovery from underwater earthquake, plane crashes into the sea, and monitoring underwater cables or piping for energy purpose are underwater missions for Remotely Operated Underwater Vehicle (ROV) in ASEAN MATE 2018 Competition. Two essentials factor to perform successfully in this ROV competition are design of an efficient communication protocol system and a low-cost communication hardware. In this research, an optimal communication system between RS-232 serial communication transmission and RS-485 serial communication transmission is developed to obtain the optimal solution. Both communication system is tested in Tech_SAS ROV-Telkom University Indonesia, a microcontroller underwater ROV based which used single microcontroller to control actuator, sensor and communication, and measured the Quality of Services (QoS) for end-to-end delay and packets loss. From the the experiment and evaluation for the two schemes, shows 12.57 ms end-to-end delay, 0% data packet error and $6 RS-485 communication system are the optimal solution for Tech_SAS ROV.

Keywords: *communication system,* explorer-class, *MATE, QoS of underwater communication, underwater ROV*

1. Introduction

The needs of underwater robot to recover underwater earthquake disaster, plane crashes into the sea, and monitoring underwater cables or piping for energy purpose are the goals of The ASEAN MATE (Marine Advanced Technology Center) in 2018. In this competition, there are three different categories: Scout, Ranger and Explorer [1]. The Explorer class, which has the most advanced vehicle specifications from other categories is choosen as the platform design in Tech_SAS team from Telkom University. With the spesification rule, clasification of Explorer class ROV can be classify as Light Work-Class ROV with weight more than 15 kgs, equiped with camera and this type ROV are carrying manipulator (grippers) [2]. In general, as shown in Figure 1, there are two systems in undewater ROV: Ground Control Station (GCS) and underwater Robot which is connected by a thether cable.

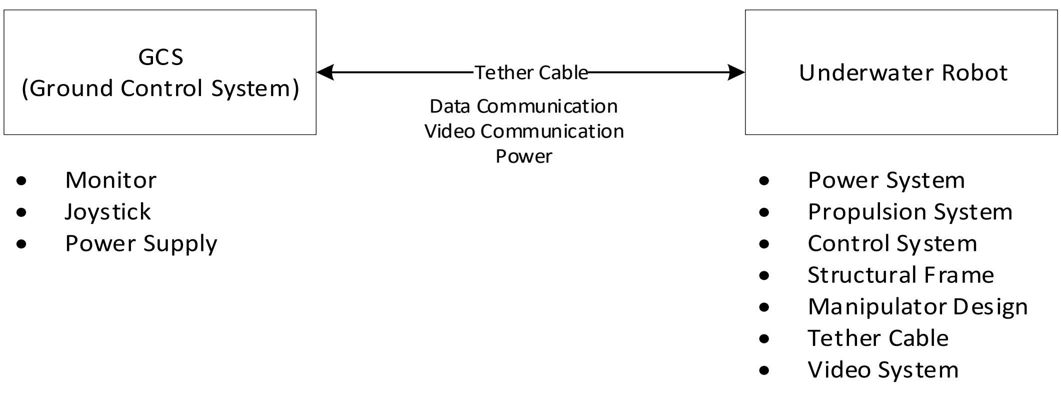


Figure 1. General design of ROV system

Received August 17, 2018; Revised November 24, 2018; Accepted December 27, 2018

Furthermore, the underwater Robot consist of seven subsystem: Power System, Propulsion System, Control System, Structural Frame, Manipulator Design, Tether Cable, and Video System [3]. Indeed, each of this sub-system is different in every design of ROV. Moreover, Ground Control Station usually consists of Display, Joystic/Gamepad and Power Suppy. In addition, thether cable usually divided into three types of cable: data communication, power, video communication.

2. Proposed Communication Protocol

To perform a mission, this underwater robot is controlled by the Gamepad/Joystick. The command from Gamepad/Joystick is sent by GCS through data communication cable to underwater robot. And then the underwater robot will execute the command through its propulsion system and/or its actuator such as manipulator. At that time, underwater robot will also send data feed back of its condition to GCS which will be displayed on the Screen.

Recent studies show several methods to send and receive information. Firstly, the methods is by using Fiber Optic as the main cable to transmit and receive data with single channel RS-232 converter between GCS and underwater robot [4]. Secondly, the main communication cable for data and video is combined in single optical cable and at the end of each fiber optical connection there is MiniMux2 board, that convert into two video channels, two RS-232 channels an one RS485 channel, is mounted at GCS and underwater robot [3]. Thirdly, the main communication cable for data and video communication is using LAN cable with Universal Asynchronous Receiver-Transmitter(UART)-SKPS is used as the main protocol [5-6]. Other research shows that the main communication cable is combined in single power line that also transmit and receive data and video with Power Line Communication (PLC) methods [7]. Wireless communication research is also already conducted using underwater accoustic communication and underwater optical communication [8-10]. Some of the researh in wireless communication is conducted in simulation method with multimodal wireless remote control [11-12]. There are three types of purposes using this wireless communication such as video, data transfer and Position and Navigation-GPS. Underwater wireless communication for position and navigation purpose is shown by using accoustic communication: ultrashort base line (USBL) [13] and long base line (LBL) [14]. An experiment shown that GPS receiver can only be used 10cm below the surface of water which means wireless communication in higher frequency is limited underwater [15-16]. With limited performance of communication protocol in underwater, a model of wireless communication protocol for realtime communication and analysis error communication to improve its performance is also shown in previous research [17-18]. A review about wired communication protocol methods that is common in ROV is shown in Table 1. Due to wireless communication protocol limitation, RS232 and RS485 wired protocol communication is choosen as the main communication protocol in this research. Both sistem will be applied in Tech_SAS ROV robot as the test bed for testing the performance.

This paper presents the optimal solution between cost and fuction in communication system for underwater ROV. This research was performed using Tech_SAS, GCS and Explorer-class Underwater Robot which developed by Robotic-SAS team from Telkom University for ASEAN MATE Underwater Robotic Competition 2018. With the summary from Table 1 and Table 2, Tech_SAS ROV with cost constraint as one of evaluation point in the competion choose wired communication scheme as the main communication method. This paper is organized as follows. Research method section describes a comparison design and implementation of the communication system in two main system-ground system and underwater Robot with RS-232 and RS485 method which separated with the video communication. The discussion of system evaluation results is presented in Results and Discussion section. Last section shows the final remarks of conclusion.

Table 1. Common Wired Protocol Communication Scheme [19]

Characteristics	Protocol		
	RS-232	RS-485	GB-Ethernet
Comms Mode	Full-Duplex	Half or Full	Half or Full
Max. Distance	15 m – 20 m	1200 m	100 m
Max. Transmission	20 kb. s^{-1}	20 Mb. s^{-1}(15m)	1 Gb. s^{-1}
Typical Logic Level	± 5 to ± 15 V	± 1.5 to ± 5 V	± 0.5 to ± 2 V

Table 2. Underwater Communication Scheme

Characteristics	Wired [19]	Wireless [20]	Optical [8], [21]
Hardware	TCP/IP Cable	Accoustic modem	Fiber optic
Max. Transmission	< 1 Gbps	< 1 kbps	< 10 Gbps
Range (in depth)	< 1500 m	< 3 m [22]	>100 km
Multiple channel	No	Yes	Yes
Needs of end-to-end converter	Yes	Yes	Yes
Cost	Low	High	High

3. Research Method

The proposed communication system block diagram is shown in Figure 2. The communication system is divided into two main system: ground system and underwater system. Tether cable consist of power cable and LAN Cable. Moreover, due to its low propation delay properties, approximately 560 nanoseconds [23], its conductivity properties, aproximately 93.8 Ohm/km, and low insertion loss(attenuation), aproximately 2.0 db/100m (according Belden Cat5e data specification sheet), the LAN Cable cat 5e is used to transmit and receive data communication and video communication. An Arduino-based microcontroller is added for controlling motor manipulator and propulsion system. In ASEAN MATE underwater, minimum tether cable length in ROV operation is 20 meters and maximum 30 meters. Meanwhile, the length of tether cable length that is used in Tech_Sas ROV is 30 meters.

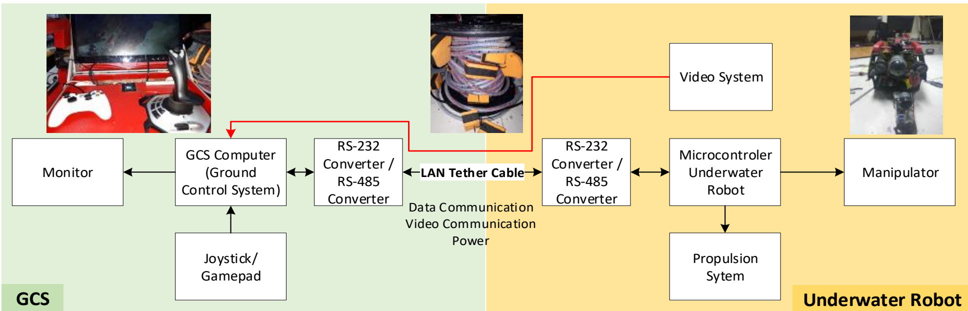


Figure 2. Proposed communication system

3.1. RS-232 Communication Tether Cable Design

The proposed RS-232 Communication tether cable design block diagram is shown in Figure 3. The communication system consists of one Converter RS-232 to USB in Ground control station and Converter RS-232 to Transistor-transitor Logic (TTL) in Underwater Robot. RS-232 Communication protocol mode is full duplex, which means this communication methods can send and receive information at the same time. Because of these properties, RS-232 only need one for each converter in Ground Control Station and in underwater robot. Figure 4 shows the converter that is used in Tech_SAS ROV for testing RS-232 Communication protocol. Moreover, Table 3 shows the development cost for developing RS-232 Communication protocol scheme.

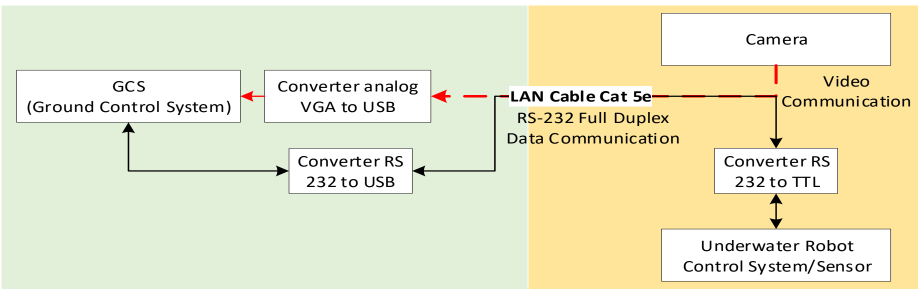


Figure 3. Proposed RS-232 communication system scheme

(a) (b)

Figure 4. Proposed RS-232 communication system scheme,
(a) USB to RS-232 Converter, (b) RS-232 to TTL converter

Table 3. Cost for RS-232 Communication Scheme

Unit	Quantity	Unit Price in US$	Price in US$
USB to RS-232 Converter	1	4	4
RS232 to TTL Conveter	1	3	3
	TOTAL		**7**

3.2. RS-485 Communication Tether Cable Design

The proposed RS-485 Communication tether cable design block diagram is shown in Figure 5. The communication system consists of one Converter RS-232 to USB and two converters RS-485 to TTL in Ground control station and two converters RS-485 to TTL in Underwater robot.

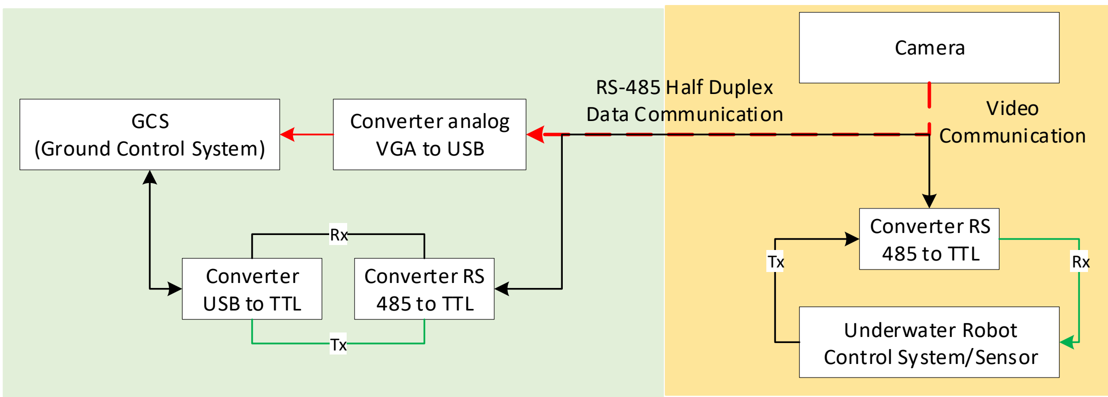
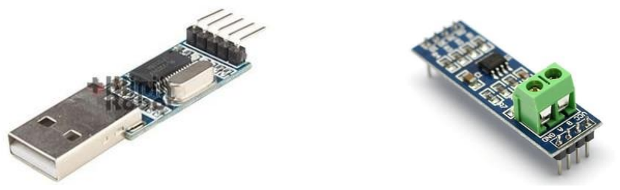


Figure 5. Proposed RS-485 communication system scheme

RS-485 Communication protocol mode is half duplex, which means this communication methods can send and receive information at one time, either only send or only receive. Because of these properties, these communication scheme need one converter in USB to TTL and two converters RS-485 which function one as sender and one as receiver in Ground Control Station and in underwater robot need two converters RS-485 to TTL which function one as sender and one as receiver. With this configuration, there is no need conversion in communication source code program in Grounc Control Station and in underwater robot. Figure 6 shows the converter that is used in Tech_SAS ROV for testing RS-485 Communication protocol. Moreover, Table 4 shows the development cost for developing RS-485 Communication protocol scheme.



(a) (b)

Figure 6. Proposed RS-485 communication system scheme, (a) USB to RS-232 Converter, (b) RS-232 to TTL converter

Table 4. Cost for RS-485 Communication Scheme

Unit	Quantity	Unit Price in US$	Price in US$
USB to TTL Converter	1	4	4
RS-485 to TTL Conveter	2	1	2
	TOTAL		**6**

3.3. Flowchart Communication System Tech_Sas Underwater Robot.

The communication software is a programme which follow the UML Sequence Diagram in Figure 7. For the proposed communication scheme, Ground Control Station and underwater Robot is programmed according the UML Sequence diagram. The communication program mechanism for sending and receiving information is described as follows.

1. Ground Control Station inisialize “hand shake” communication connection with underwater robot. This procedure is to notify each system that Ground Control System and Underwater Robot is ready to communicate.
2. After “hand shake” inisialize is correct and match, then Ground Control System will start to send “command” and wait underwater robot to send reply “state of underwater robot”. If there is no “state” reply from underwater robot, it means there is a problem in this connection.
3. On the other side, after finish inisialize “hand shake” process, underwater robot will wait “command” from Ground Control System. If there is a command, then underwater robot will execute the command accordingly and send “state of underwater robot” to Ground Control Station.

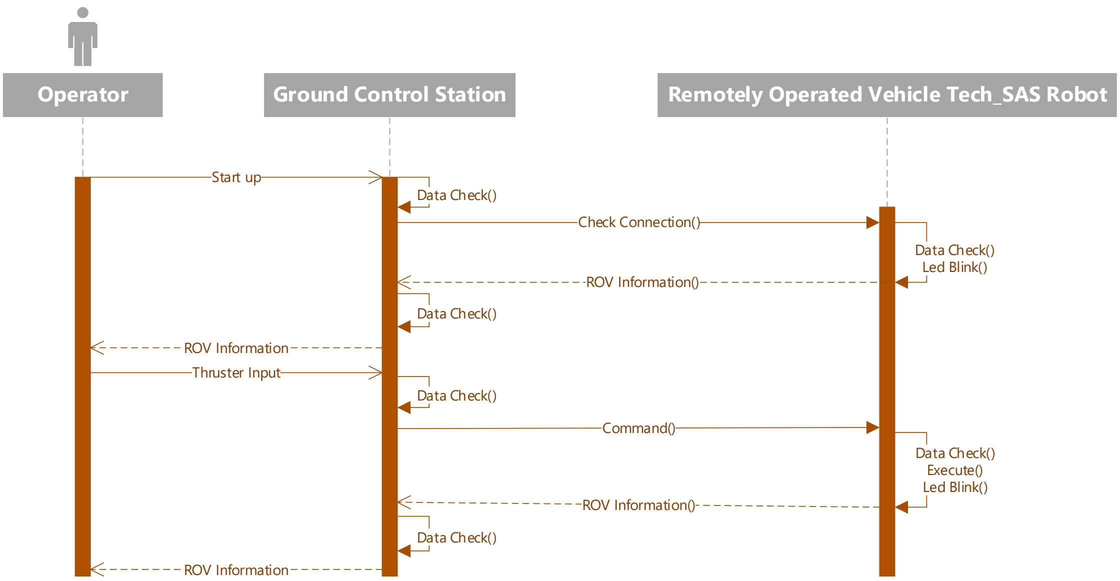


Figure 7. UML sequence diagram for the proposed communication system scheme

4. Results and Analysis
4.1. Communication Experiment Result

Measurement in Quality of Service (QoS) is measurement of performance in packet transfer. There are several aspects that are often sonsidered, such as packet loss, bit rate, throughput, end-to-end delay, availibility and jitter [24]. In this research, packet loss and delay is two main factors for underwater robot to perform its capability. End-to-end delay is a total time taken for a packet of data sent from source to destination of a system [25]. The end-to-end delay in this research is a summation of processing delay, packetization, transmission delay, propagation delay and queueing delay from given command with Gamepad/Joystick in Ground Control Station and start an actuator movement in Underwater Robot. In Tech_SAS ROV robot, there are aproximately 6 ms processing encapsulation time in Ground Control Station and aproximately 6 ms processing decapsulation time in Underwater Robot. Packet loss is a percentage of packets lost with respect to packet sent.

Table 5 and Table 6 shows the experiment result of the two communication methods. In that table, RS-232 scheme shows there is no loss packet loss in length of 15-20 meters which is slightly different with the properties of RS-232 communication scheme in proposed communication introduction. Even though there is only small increasing in average end-to-end for different tether cable length, the average delay is 11.45 ms. In RS-485 scheme, due to its long maximum transmission range properties, there is an increasing on end-to-end delay time as addition to different working volatage properties of RS-485 communication module. The average delay is 11.47 ms.

Table 5. Experiment Result with 10 Trial Data for RS-232 Communication Scheme without CRC

Tether Cable Length	Command	Average delay (ms)	Response Accuracy	Error Percentage (%)
5	Move Forward	11.2	Match	0%
10	Move Forward	11.4	Match	0%
15	Move Forward	11.8	Match	0%
20	Move Forward	11.5	Match	0%
25	Move Forward	11.4	Match	0%
30	Move Forward	11.4	Match	0%

Table 6. Experiment Result with 10 Trial Data for RS-485 Communication Scheme without CRC

Tether Cable Length	Command	Average delay (ms)	Response Accuracy	Error Percentage (%)
5	Move Forward	11.3	Match	0%
10	Move Forward	11.8	Match	0%
15	Move Forward	11.4	Match	0%
20	Move Forward	11.4	Match	0%
25	Move Forward	11.6	Match	0%
30	Move Forward	11.2	Match	0%

4.2. Communication Experiment Result with Cyclic Redundancy Check

Table 7 and Table 8 shows the experiment result of the two communication methods with Cyclic Redundancy Check (CRC)[11][26]. CRC is a method that is used to detect accidental or non-accidental changes to raw data. With this method, the number of packet loss is expected to be decrease. In both communication methods are added with CRC at both end of the system. And the experiment result show that there are increasing of end-to-end delay but with smaller number of packet loss. From the previous experiment, without CRC, both RS-232 and RS-485 communication scheme show increasing of average delay due to processing time addition for CRC. There is approximately 1 ms average delay for each communication scheme. The average delay of RS-232 and RS-485 are 12.76 ms and 12.57 ms. Error Percentage shows the average error for different tether cable length. In this experiment, both proposed communication scheme performs the same properties with no cyclic redundancy check applied in the system.

Table 7. Experiment Result with 10 Trial Data for RS-232 Communication Scheme with CRC

Tether Cable Length	Command	Average delay (ms)	Response Accuracy	Error Percentage (%)
5	Move Forward	12.3	Match	0%
10	Move Forward	12.5	Match	0%
15	Move Forward	12.5	Match	0%
20	Move Forward	12.4	Match	0%
25	Move Forward	12.9	Match	0%
30	Move Forward	12.8	Match	0%

Table 8. Experiment Result with 10 Trial Data for RS-485 Communication Scheme with CRC

Tether Cable Length	Command	Average delay (ms)	Response Accuracy	Error Percentage (%)
5	Move Forward	12.6	Match	0%
10	Move Forward	12.6	Match	0%
15	Move Forward	12.8	Match	0%
20	Move Forward	12.8	Match	0%
25	Move Forward	13	Match	0%
30	Move Forward	12.8	Match	0%

4.3. Analysis of Design and Experiment Result

From design and experiment, Table 9 shows that both communication scheme can execute underwater mission with good performe 0% packet loss in Tech_SAS underwater robot with and without CRC. With slightly 1ms time different for end-to-end delay, both communication scheme in addition to CRC processing time also shows can perform underwater mission adequetly. Furthermore, both communication scheme has low-cost development price with only $1 different. With this different, RS-485 is the optimal solution of low-cost development for underwater ROV communication.

Table 9. Comparison for RS-232 and RS-485 Communication Scheme

Parameter	RS-232	RS-485
Best Performance Length (Theory)	15-20 m	1200 m
Best Performance Length (Experiment)	0-30 m	0-30 m
Max. Packet Loss (without CRC)	0%	0%
Max. Packet Loss (with CRC)	0%	0%
End-to-end delay (without CRC)	11.45 ms	11.47 ms
End-to-end delay (with CRC)	12.76 ms	12.57 ms
Cost	Low ($7)	Low ($6)

5. Conclusion

The research presented shows that both RS-232 scheme and RS-485 can perform well. In RS-232 communication scheme, there is several researches shows that RS-232 only work under 20m, but in this research, both proposed communication scheme performs as designed. In brief, with the requirement of tether cable length 20-30 meter and the constrain of development cost in ASEAN MATE competition, the optimal solution for communication system for TECH_SAS robot is RS-485 communication methods with 0% data packet loss and 12.57ms end-to-end delay. There are several methods that can be done in the future to improve the capability of data and video communication such as the implementation of TCP/IP methods, acoustic modem methods, and optical fiber communication methods.

Acknowledgment

This research was supported and funded by *Riset Desentralisasi-Penelitian Terapan Unggulan Perguruan Tinggi (*PTUPT) from Ministry of Research, Technology, and Higher Education, Indonesia. This work was also supported by Embedded and Network System Research Laboratory and Robotic SAS team, Faculty of Applied Science, Telkom University.

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