DESIGN AND IMPLEMENTATION OF ELECTRONIC LOGGING INSTRUMENT TO HELP SCIENTIFIC DIVER IN CORAL REEF MONITORING

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ABSTRACT

Indonesia is situated in the Coral Triangle region that has the world's highest coral reef biodiversity. Therefore, coral reef monitoring needs to be conducted regularly to assess the condition of coral reef ecosystem for management purpose. There are several coral reef monitoring methods available such as the line intercept transect (LIT), point intercept transect (PIT), photo transect, belt transect and benthic towed-diver. In Indonesia, LIT and PIT are the most commonly used methods for coral monitoring. However, there is a main disadvantage when collecting data using these methods, that is scientific divers need to spend hours to input the data after dives. Here, we introduce an electronic logging instrument called Coral Input Data Instrument that helps to decrease the input data time by employing a look-up table system that simplifies data input process by replacing text with numerical coding. In addition, water quality data such as temperature, depth and visibility also are embedded in the electronic logging instrument. The instrument hardware consists of Arduino Mega 2560, keypad 4x3, LCD Module 16x2 character, real time clock, temperature sensor, pressure sensor, visibility sensor and micro SD card module. Arduino IDE 1.6.5 software is used to program the microcontroller. In this paper, we describe the design and implementation of the instrument in the field.

Keywords: instrumentation, coral reef monitoring, water quality, Arduino

INTRODUCTION

Coral reef condition is linked to natural factors and human activities. Changes caused by nature versus human activity are markedly different, therefore monitoring the impacts of human activities on coral reef ecosystems is important. To do this, field monitoring needs to be conducted regularly. Data from such observation are key to plan and assess coral reef management strategies.

Coral monitoring methods advance with technological development. Some commonly used methods are the line intercept transect (LIT), point intercept transect (PIT), photo transect, belt transect and benthic towed-diver (NOAA, 2015). The methods that are often used in Indonesia are LIT and PIT. LIT typically uses coral life-form categories and codes of English *et al.* (1994). Whereas the application of PIT in Indonesia could adopt the codes established by COREMAP-LIPI (Manuputty and Djuwariah, 2009).

Technology that allows data collection from coastal oceans in real time are important to a wide range of societal elements including academics/ researchers, the military, resource managers, and marine safety and commercial operators. For instance, having real-time measurements could improve the management of accidents involving hazardous materials, as well as increase the effectiveness of marine environmental monitoring. Coastal ocean data are well suited for real time measurement since they can be collected on platforms with reliable and frequent communication with the shore or land.

For coral reef monitoring, scientific diver usually carries a slate with waterproof paper to record types of observed corals. Then the data are entered into a computer for further data processing. Considering many field observations that need to be conducted across the archipelago, divers have expressed a common issue with the amount of time needed to input the data to the computer that could take hours. Or worse, sometimes the diver cannot read the data that were written in the field. These disadvantages motivate us to facilitate scientific divers by creating an instrument that allows efficient coral data input. The instrument consists of a computer so that data obtained in the field can be processed automatically when inputted into the computer. In this paper, we also introduce a look up table system incorporated into the instrument.

MATERIALS AND METHODS

The first requirement for the instrument is that it has to be waterproof. Here, we design a waterproof case using Solidwork program. Inside the case, the placement of components is arranged using a design built by RepRap 3D Printer.

The instrument also has to function as an underwater e-logbook, by assisting scientific divers to record coral data, measure water quality data and store both information in a micro SD card. Therefore the hardware of this instrument consists of Arduino Mega2560, real time clock DS1370, temperature sensor DS18B20, pressure sensor MPX5700, light sensor TEMT6000, ADC (analog to digital converter) 16 bit ADS1115, green laser (532nm), keypad 4x3, LCD 16x2 character and micro SD card module.

All of these components are combined and simulated in Labcenter Electronics Proteus 8. Arduino firmware written using Arduino IDE 1.6.5. Simulated data are stored in virtual SD card file that is opened using WinImage.

The instrument is designed so that it could record coral data inputted manually by diver during coral monitoring surveys, but automatically records water quality parameters (temperature, depth, and visibility range). Temperature data is obtained from DS18B20 using 1 Wire communication. Depth data is obtained from MPX5700 from pressure, following a formula by Fofonoff & Millard (1983):

$$h = [(((-1.82\text{x}10\text{-}15\text{*}p+2.279\text{x}10\text{-}10)\text{*} \\ p\text{-}2.2512\text{x}10\text{-}5)\text{*}p+9.72659)\text{*}p]/g$$

where:
h = depth (m)
p = pressure (decibar)
g = gravity (9.8 m.s^{-2})
Note : 1 Pascal = 0.0001 decibar or 10-5 bar.

Visibility range is obtained using green laser and light sensor TEMT6000. This visibility measurement adopts the method by Zanezeld & Pegau (2003) which has been modified from Duntley (1963) and Preisendorfer (1976). The light sensor yields values as light transmission coefficient which are converted to attenuation coefficient following:

where:

$$Tr = \frac{DN(l)}{DN(0)}$$

Tr = Transmission Coefficient
DN (l) = Digital Number on 10 cm
DN (0) = Digital Number on 1 cm
The transmission coefficient then is used to get green laser attenuation coefficient:

where:
cg = Green laser attenuation coefficient (m-1)

$$c_g = \frac{-1}{l} \times lnTr$$

l = distance between laser and light sensor (10 cm)
Tr = Transmission coefficient

Then, the green laser attenuation coefficient is used to obtain attenuation coefficient (α) following:

From attenuation coefficient, visibility range (y) can be computed as:

$$\alpha = c_g \times 0.9 + 0.081$$

$$y = 4.55 / \alpha$$

Two coral monitoring methods, LIT and PIT, are accommodated by the instrument. When the user selects LIT, the inputs are form and genus type codes following coral categories of English *et al.* (1994) and Veron (2000) as shown in Table 1 and Table 2. For example, the user would enter number 2 (ACD) for life-form category when observing *Acropora* Digitate and enter number 2 for genus code because this life-form belongs to the genus *Acropora*. If the user selects PIT, the inputs are the numerical codes representing forms as shown in Table 3. This form code follows the guideline established by COREMAP-LIPI (Manuputty and Djuwariah, 2009).

Table 1. Type of life-form categories and codes based on English *et al.* (1994).

Category	Lifeform	Code	Note
Hard Coral Live	ACB	01	*Acropora* Branching
	ACD	02	*Acropora* Digitate
	ACE	03	*Acropora* Encrusting
	ACS	04	*Acropora* Submassive
	ACT	05	*Acropora* Tabluar
	CB	06	Non-*Acropora* Branching
	CE	07	Non-*Acropora* Encrusting
	CF	08	Non-*Acropora* Foliose
	CM	09	Non-*Acropora* Massive
	CS	10	Non-*Acropora* Submassive
	CHL	11	Heliopora
	CME	12	Millepora
	CMR	13	Mushroom
Dead Coral	DC	14	Dead Coral
	DCA	15	Dead Coral Algae
Algae	AA	16	Alga Asembly
	CA	17	Coraline Algae
	HA	18	Halimeda
	MA	19	Macro Algae
	TA	20	Turf Algae
Biotic	OT	21	Other
	SC	22	Soft Coral
	SP	23	Sponge
	ZO	24	Zoanthid
Abiotic	R	25	Rubble
	ROCK	26	Rock
	S	27	Sand
	Si	28	Silt

Table 2. Type of genus based on Veron (2000).

Genus	Family	Code	Genus	Family	Code	Genus	Family	Code
Acanthastrea	Mussidae	1	*Eusmilia*	Meandrinidae	38	*Oculina*	Oculinidae	75
Acropora	Acroporidae	2	*Favia*	Faviidae	39	*Oulastrea*	Faviidae	76
Agaricia	Agariciidae	3	*Favites*	Faviidae	40	*Oulophyllia*	Faviidae	77
Alveopora	Poritidae	4	*Fungia*	Fungiidae	41	*Oxypora*	Pectiniidae	78
Anacropora	Acroporidae	5	*Galaxea*	Oculinidae	42	*Pachyseris*	Agariciidae	79
Anomastraea	Siderastreidae	6	*Gardineroseris*	Agariciidae	43	*Palauastrea*	Astrocoeniidae	80
Astrangia	Rhizangiidae	7	*Goniastrea*	Faviidae	44	*Paraclavarina*	Merulinidae	81
Astreopora	Acroporidae	8	*Goniopora*	Poritidae	45	*Parasimplastrea*	Faviidae	82
Australogyra	Faviidae	9	*Gyrosmilia*	Meandrinidae	46	*Pavona*	Agariciidae	83
Australomussa	Mussidae	10	*Halomitra*	Fungiidae	47	*Pectinia*	Pectiniidae	84
Balanophyllia	Dendrophylliidae	11	*Heliofungia*	Fungiidae	48	*Physogyra*	Euphyllidae	85
Barabattoia	Faviidae	12	*Herpolitha*	Fungiidae	49	*Platygyra*	Faviidae	86
Blastomussa	Mussidae	13	*Heterocyatus*	Caryophylliidae	50	*Plerogyra*	Euphyllidae	87
Boninastrea	Merulinidae	14	*Heteropsammia*	Dendrophylliidae	51	*Plesiastrea*	Faviidae	88
Cantharellus	Fungiidae	15	*Horastrea*	Siderastreidae	52	*Pocillopora*	Pocilloporidae	89
Catalaphyllia	Euphyllidae	16	*Hydnophora*	Merulinidae	53	*Podabacia*	Fungiidae	90
Caulastrea	Faviidae	17	*Indophyllia*	Mussidae	54	*Polyphyllia*	Fungiidae	91
Cladocora	Faviidae	18	*Isophyllia*	Mussidae	55	*Porites*	Poritidae	92
Coeloseris	Agariciidae	19	*Leptastrea*	Faviidae	56	*Poritipora*	Poritidae	93
Colpophyllia	Faviidae	20	*Leptoria*	Faviidae	57	*Psammocora*	Siderastreidae	94
Coscinaraea	Siderastreidae	21	*Leptoseris*	Agariciidae	58	*Pseudosiderastrea*	Siderastreidae	95
Ctenactis	Fungiidae	22	*Lithophyllon*	Fungiidae	59	*Sandalolitha*	Fungiidae	96
Ctenella	Meandrinidae	23	*Lobophyllia*	Mussidae	60	*Scapophyllia*	Merulinidae	97
Cycloseris	Fungiidae	24	*Madracis*	Astrocoeniidae	61	*Schizoculina*	Oculinidae	98
Cynarina	Mussidae	25	*Manicina*	Faviidae	62	*Scolymia*	Mussidae	99
Cyphastrea	Faviidae	26	*Meandrina*	Meandrinidae	63	*Seriatopora*	Pocilloporidae	100
Dendrogyra	Meandrinidae	27	*Merulina*	Merulinidae	64	*Siderastrea*	Siderastreidae	101
Diaseris	Fungiidae	28	*Micromussa*	Mussidae	65	*Simplastrea*	Oculinidae	102
Dichocoenia	Meandrinidae	29	*Montastrea*	Faviidae	66	*Solenastrea*	Faviidae	103
Diploastrea	Faviidae	30	*Montigyra*	Meandrinidae	67	*Stephanocoenia*	Astrocoeniidae	104
Diploria	Faviidae	31	*Montipora*	Acroporidae	68	*Stylaraea*	Poritidae	105
Duncanopsammia	Dendrophylliidae	32	*Moseleya*	Faviidae	69	*Stylocoeniella*	Astrocoeniidae	106
Echinomorpha	Pectiniidae	33	*Mussa*	Mussidae	70	*Stylophora*	Pocilloporidae	107
Echinophyllia	Pectiniidae	34	*Mussismilia*	Mussidae	71	*Symphyllia*	Mussidae	108
Echinopora	Faviidae	35	*Mycedium*	Pectiniidae	72	*Trachyphyllia*	Tracyphylliidae	109
Erythrastrea	Faviidae	36	*Mycetophyllia*	Mussidae	73	*Turbinaria*	Dendrophylliidae	110
Euphyllia	Euphyllidae	37	*Nemenzophyllia*	Euphyllidae	74	*Zoopilus*	Fungiidae	111

Table 3. Point Intercept Transect Codes

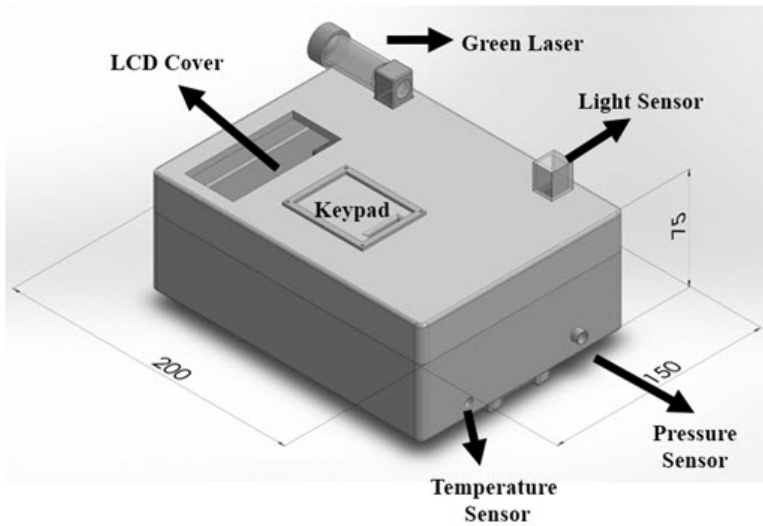| CODE	CATEGORY	NOTE
1	HCL	Hard Coral Live
2	HCD	Hard Coral Dead
3	SC	Soft coral
4	AL	Algae
5	OT	Other

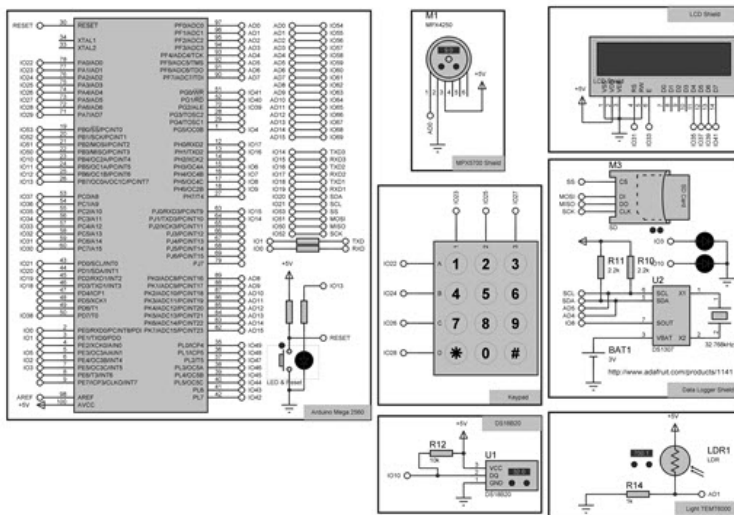**Figure 1.** Coral input data instrument case design and dimension

Figure 2. Coral input data instrument electronic schematic used in Proteus 8

RESULTS

SYSTEM DESCRIPTION

This electronic logging instrument which we name 'Coral Input Data Instrument' has a dimension of 200mm x 150mm x 75mm (Figure 1). The upper part consists of LCD, keypad attachment and visibility sensor. The bottom part consists of Arduino Mega2560, battery, pressure sensor, temperature sensor, ADC 16bit, real time clock, micro SD card module and LCD module. This outer case is built from polylactic acid using a 3D printer.

The Coral Input Data Instrument uses 8-bit ATMEL microcontroller ATMega2560. This microcontroller has 86 programmable IO pins (ATMEL, 2014) and is embedded into Arduino Mega2560 board. Some important features used in this instrument include serial peripheral interface (SPI), inter-integrated circuit (I2C), one wire communications and some digital gates. The circuit schematic is shown in Figure 2.

Following the flow chart shown in Figure 3, the microcontroller starts by prompting "Coral ID System" on the LCD display and then initializing the micro SD card. If no micro SD card is detected, the instrument would not proceed to the next command and the LCD would display the text "Init failed!" instead. If the initialization is successful then the command would proceed with initializing DS18B20. The, the microcontroller would send an electronic signal containing the address register DS18B20. If DS18B20 is not found, then the LCD would display the text "DS18B20 ERROR". If initialization is successful, the LCD would display the text "DS18B20 OK" and proceed to the next command. Next, DS1307 RTC initialization is used to retrieve the data time and date. If the DS1307 is not found or has not been programmed, then it would display the text "Error. Please run the setTime" which means that the user must run firmware setTime or check the circuitry in case of errors in the DS1307 RTC installation.

Next, the user must choose a coral survey method: 1. PIT (point intercept transect) or 2. LIT (line intercept transect). This option would be used for naming files that are stored in the micro SD card. Station number is entered manually by the user. If the same station number is already entered in the micro SD card, the LCD would display "ALREADY AVAILABLE" and the user must enter a new station number. The method used and the number of the station would from the file name in the format of METHOD_NO STATION.TXT.

Then, the microcontroller would take the laser transmission data from the light sensor TEMT6000 which is converted into digital values from analog values using the ADS1115 ADC. The ADC works to increase the resolution to 16bit. Transmission value is converted into a value of visibility and displayed on the LCD. Then, the transmission data is stored in a file created earlier. The microcontroller also takes temperature data from DS18B20, displays on the LCD and stores it in a file that has been created. The microcontroller retrieves data from MPX5700 depth sensor. The depth value is obtained from converting pressure. The depth value is displayed on the LCD and also stored on the micro SD Card.

If the method chosen is PIT, the user inputs a code following Table 3 and when the user presses '#', the microcontroller would take depth data and store it along with the code inputted earlier in the micro SD card. If the chosen method is LIT, then the user must enter the distance, shape, and genus according to Table 1 and Table 2. And when the user presses '#', the microcontroller would take the data and store it along with the depth, transition distance, shape and genus codes inputted earlier in the micro SD card.

PROTEUS SIMULATION

Simulation in Proteus is used to see Coral Input Data Instrument's performance from firmware compiled by Arduino IDE by inserting coral data using LIT and PIT simulated in this software. The simulation follows schematic shown in Figure 2.
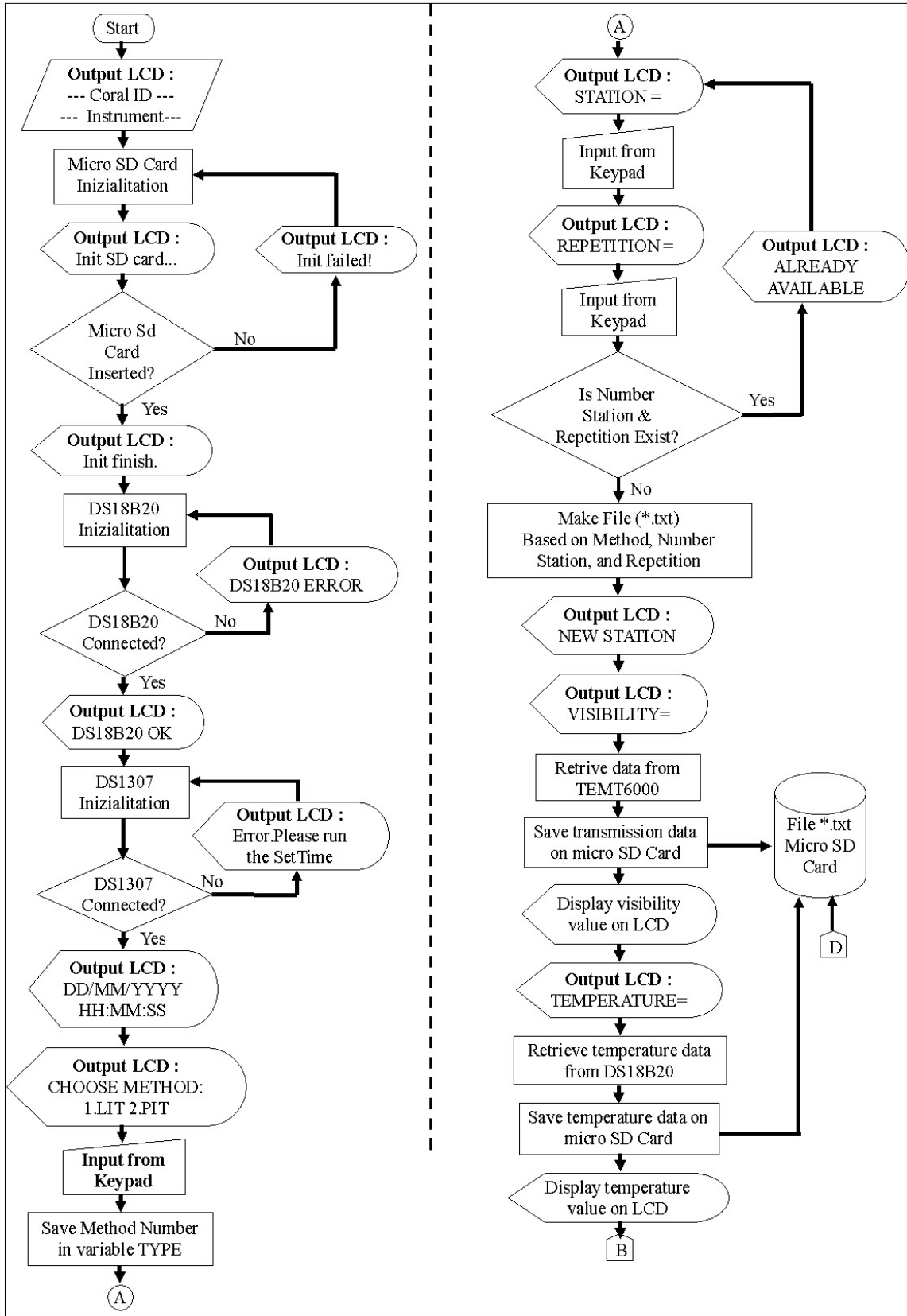
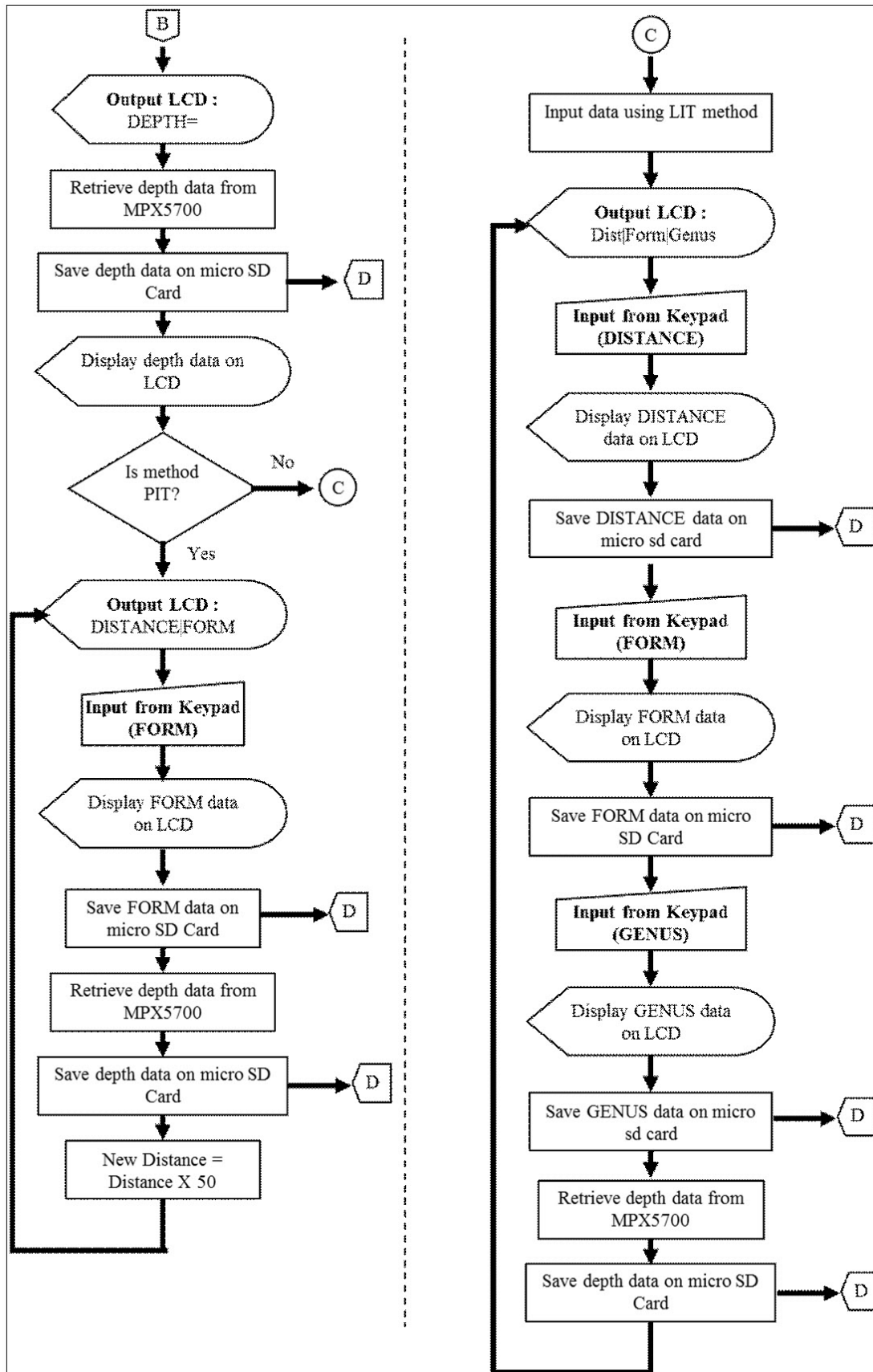**Figure 3.** Coral Input Data Instrument flow chart.

Figure 3 (Continued). Coral Input Data Instrument flow chart.

In LIT simulation, Coral Input Data Instrument succeeded in retrieving temperature, depth, and visibility data (Figure 4), while the user input coral data manually as shown in Figure 5. Data stored on virtual SD card is opened using WinImage software (Figure 6) and saved as text file (*.txt). This text file contains temperature data, depth, visibility, transition distance, form and genus codes (Figure 7).

In PIT simulation, temperature data, depth and visibility show the same results as shown in Figure 4. In this simulation, the only need to input category code number between 1 to 5 according to Table 3 (Figure 8). Other numbers would not be recognized by the instrument. The PIT coral input data are also stored in virtual SD card and opened using WinImage as text file. This file contains temperature data, depth, visibility, transition and form code (Figure 9).
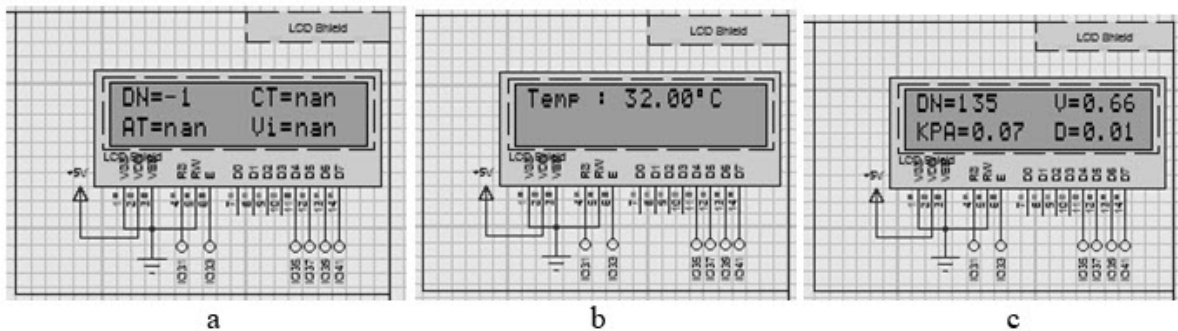

Figure 4. Data display on LCD during simulation. a = visibility, b = temperature, and c = depth.
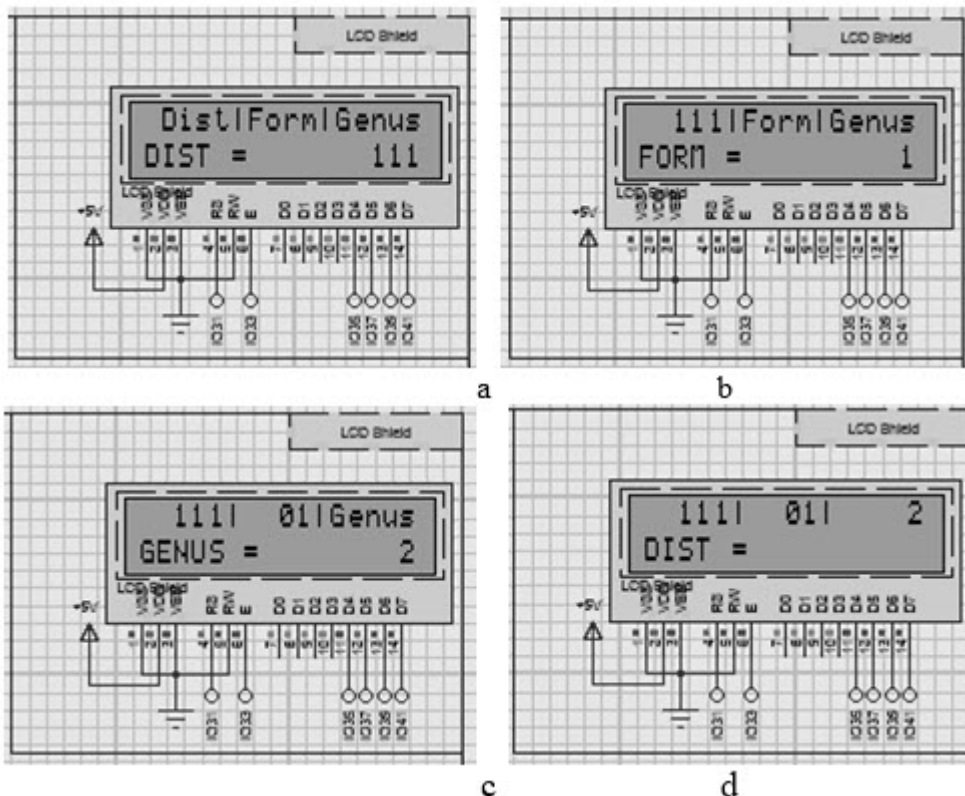

Figure 5. Step-by-step on inputting of coral data. a. User inputs transition distance, b. user inputs FORM code, c. user inputs GENUS code, d. user pushes # button to store the data in micro SD card and user inserts the next transition.
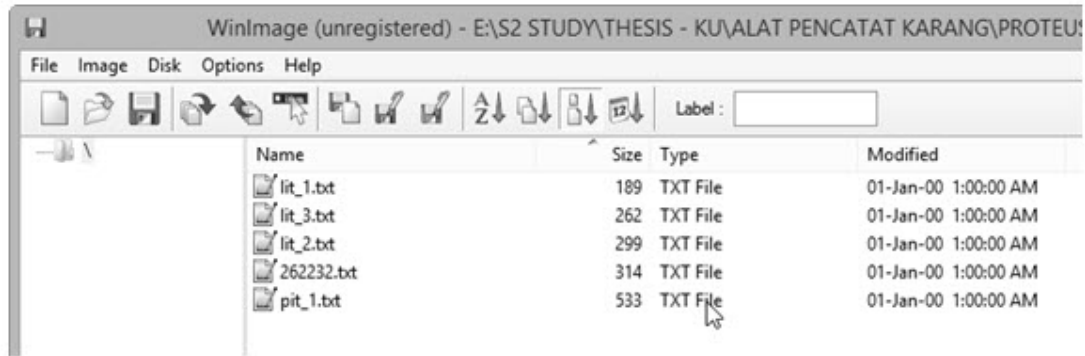
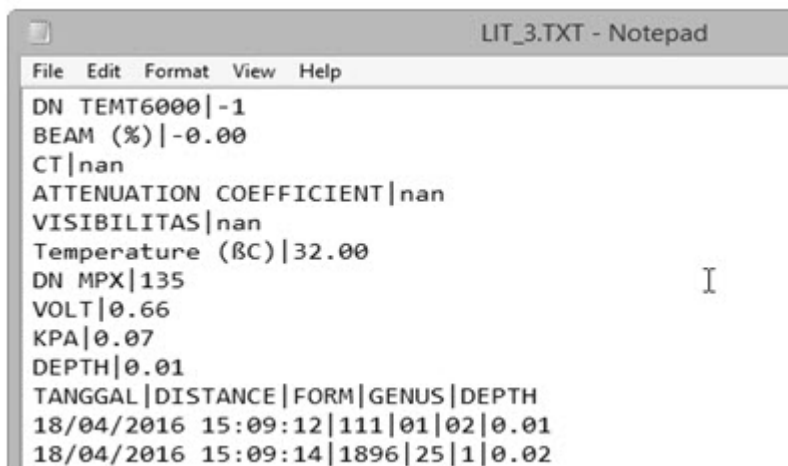**Figure 6.** WinImage software and coral survey data stored in virtual SD card.

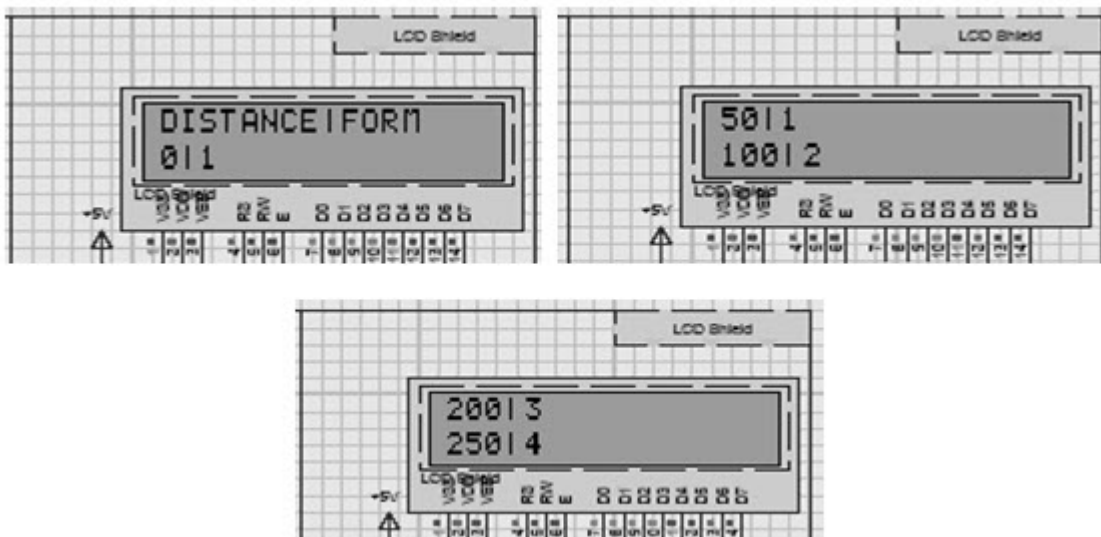**Figure 7.** Text file containing sensor data and coral input using LIT method that is stored in virtual SD card.

Figure 8. Coral input data using PIT method.

Figure 9. Text file containing sensor data and coral input using PIT Method that is stored in virtual SD card.

Figure 10. Diver using the Coral Input Data Instrument to record coral life-form and genus types using LIT and PIT methods.

Figure 11. Powerbank USB hole exposed by short-circuit

FIELD OBSERVATION

Field observation and test was conducted in Pramuka Island to assess performance of the instrument in the field. The Coral Input Data Instrument succeeded during the field test (Figure 10), both in LIT and PIT methods. This instrument could decrease data input time about 50 percent for PIT method and almost same for LIT method (Table 4). The problem that occurred during the field test was waterproofing and buoyancy issues. The instrument could not stay for long at 6 m depth, where the case leaked to cause electrical short-circuit. The supply was burned and could not be used anymore (Figure 11). This happened because seawater is a good element to conduct electricity. Also, the instrument has positive buoyancy due to space inside the instrument.

Table 4. Comparison of coral life-form and genus data retrieval times between manually inputted versus by using the instrument/

METHOD	REPETITION	MANUAL	INSTRUMENT
Point Intercept Transect	1	6 minute 15 second	3 minute 41 second
	2	6 minute 25 second	3 minute 21 second
Line Intercept Transect	1	14 minute 53 second	18 minute 43 second
	2	15 minute 17 second	18 minute 21 second
	3	14 minute 10 second	14 minute 57 second

DISCUSSION

Simulation is an important step in designing and implementing an instrument. Both hardware, and firmware (software) need to be designed. But often, there is no standard for hardware platform and with many options to be considered when selecting hardware components. Having simulation before making the instrument would save many hours of prototype development because changing components in a hardware circuit is not an easy task after building the whole circuit as it requires cost and time (Cika and Grundler, 2010; Mohammed and Devaraj, 2013). Therefore, simulation is used to decrease the cost and time before manufacturing an instrument (Su and Wang, 2010; Xinhuan *et al.*, 2010). With simulations, the circuit can be modified at any stage until the expected performance and results are obtained. Then, simulation results with a particular hardware configuration can be compared for analysis.

Labcenter Electronics Proteus is often used by engineer to simulate electronic schematic and instrument based on microcontroller (Su and Wang, 2010; Xinhuan *et al.*, 2010; Xiumei and Jinfeng, 2011; Mohammed and Devaraj, 2013). This software is popular because there are many components that can be used from the library, circuit simulation's interactive, and real time simulation.

Simulation conducted in developing the of Coral Data Input Instrument is very helpful for evaluating firmware code used in this instrument. We can check and fix errors that appear in firmware code. Electronics simulation using Proteus also helps us to ensure that the connections of each electronic component are in the right place. Wrong connection could result in damage to electronic components.

The Coral Input Data Instrument is an innovation that could help scientific divers in recording coral reef data using LIT and PIT methods. Some researchers use ROV (Lam *et.al.,* 2006) or Catlin Seaview Survey (González-Rivero *et al.*, 2014), but these instruments are expensive. The Coral Input Data Instrument is a cheaper option.

The Coral Input Data Instrument has several advantages, such as it could reduce data recording time, record water quality parameters automatically, and decrease time for inputting data into computer. This instrument also has several disadvantages being new/unfamiliar to divers, having a positive buoyancy case and waterproofing issue.

CONCLUSION

The design process for creating the Coral Input Data Instrument has been using Labcenter Electronic Proteus with respect to efficiency, quality and flexibility. With simulations, any problem in firmware can be checked and fixed before manufacturing the instrument. Field test observation shows that the instrument was able to work underwater for several hours, record water quality parameters automatically and decrease time for inputting data into computer. Improvements are still needed for waterproofing and buoyancy to create a fully functioning instrument. Future work also includes building a converter program to provide coral data from numeric to life-form and genus types.

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