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Development of a Low-cost Arduino-based Patient Monitoring System for Heartrate, Oxygen Saturation and Body Temperature Parameters

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Abstract: The implementation of Patient Monitor (PM) in the intensive care unit (ICU), intensive coronary care unit (ICCU) and neonatal intensive care unit (NICU), as well as in a pediatric intensive care unit (PICU) are currently imposes a significantly high cost of investment. According to studies conducted, there are three main parameters required to be measured, which are heartrate (BPM), oxygen saturation (SPO2) and body temperature (T). These are highly needed by the medical personnel to monitor in order to determine patient's vital state. The low-cost patient monitor prototype (named Patient Monitor 3 Parameters or PM3P) was developed using Arduino platform. In order to measure the parameters, two types of sensor modules were chosen, namely MAX30100 for gathering heartrate and oxygen saturation data and DS18B20 for gathering the body temperature data. The prototyping process also included fixation and finalization of electrical circuit on a printed circuit board (PCB). The PM3P underwent extensive validation process by comparing it to the real industrial PM made by healthcare equipment industry. The comparison was done over data gathered by both system that were conducting the same measurement runs in parallel. Results of validation indicates that the low-cost patient monitor prototype has a slight error of 0,31% for heartrate and 1,59% for oxygen saturation compared to the industrial one. Further improvements for the Arduino based PM3P are also proposed in this paper in order to enhance its reading accuracy, namely calibration.

Keywords: patient monitoring system; low-cost Arduino-based devices, intensive care unit

1. Introduction

The investment for Patient Monitor equipment in ICU, ICCU, PICU and NICU does truly emerge to be an actual issue as it needs a very costy expense. A unit might price around 30-50 million rupiahs. According to the data from Health Ministry of Indonesia in 2016, only 16,5% from the whole Indonesia's hospitals have already owned such facility [1]. Patient Monitor becomes an option, because the medical data it has proceeded represents patient's physical state.

From all the parameters in Patient Monitor, three are chosen as main preference: heartrate (BPM), oxygen saturation (SPO2), dan body temperature (T). The reason is that those parameters have all data being highly needed by the medical personnel to enable them determine patient's vital state. So, with affordable cost, the development of Patient Monitor 3 Parameter (PM3P) based on

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Arduino can drastically reduce the high investment of Patient Monitor. And its prototype development may open another way of Patient Monitor's procurement with additional parameters (i.e., PM6P) years later.

Heartrate parameter has a role to measure the heart's ability of regulating blood circulation and the metabolism of mechanism on one's body as well. Oxygen saturation literally determines the blood's oxygen level. The purpose of body temperature parameter is to fully perceive the regulation system on patient's body. The normal people's heartrate generally reaches the range between 60-100 BPM (beat per minute) [2]. As for the oxygen saturation, the normal rate of oxygen level is on the range of 97% + 2% level [3]. And the body's temperature normal range occurs around 36-37,4 ^{0}C [4]. If the heartrate parameter is not in normal range, it implies that one has such health issue in which it need be checked further. Therefore, the obvious impact related to oxygen saturation parameter is the oxygen's supply deficit to brain and other organs too that might lead into health issues like breathing problems and headache. As for body temperature parameter, thus does highly come fever's symptoms and even lead into tissues and organs' failure; not to mention death.

Patient assessment's procedure apparently becomes a notable aspect to gainfully acquire result with good quality for all the three parameters mentioned above. It basically consists of three principal regards. The first is to avoid assessment in standing position yet talking with others [5]. Also, medical personnel do actually advise the assessment to be run after patient halting from any activity around 15-30 minutes [6]. And the latter has major effect in which the hand must be placed parallel with the heart according to clinical provision.

Generally, based on the heartrate parameter's result, the well-known heart defects are namely bradycardia (under normal range, quite slow beat) and tachycardia (over normal range and beating very fast) [7]. Further, several factors remarkably affect blood oxygen level such as age, body temperature blood pH, partial CO2 and O2 pressure, also sea level altitude and barometric pressure too [3]. And as for body temperature parameter, here are the following causes of fever: endangering illness; tissues' defect; influence of drug; inflammation; and so forth [4].

All the aforesaid parameters that determine patient's vital state are measured and all the data from these parameters is being gathered, then processed by various sensors intended for every available parameter. Those sensors are actually being connected to a device in which it does simply integrate the result from all parameters. Later, we recognize it as Patient Monitor. Rather, Patient Monitor has a role to map all result from each parameter through connected sensors properly in order to simplify the diagnose from medical personnel. Moreover, there are varied kinds of Patient Monitor due to its parameters' amount. From three parameters, also five, till the most amount in which it reaches seven parameters. The measured parameters are as followings: heartrate; oxygen saturation; body temperature; respiratory rate; carbon dioxide level; blood pressure; and blood sugar level. This paper aims to report the design and development of our low-cost patient monitoring system for supported with Arduino-based platform for heartrate, Oxygen saturation and temperature of the human body.

2. Materials and Methods

Illustration of the main outline for design and prototype development of low cost PM3P based on Arduino is presented on Fig. 1. The initial step began from doing literature study towards health and electronic equipment aspect as well; along with the method of making simple Patient Monitor. The Next is to choose the sensor modules which can fully provide all the need for PM3P yet preferably have the finest performance.

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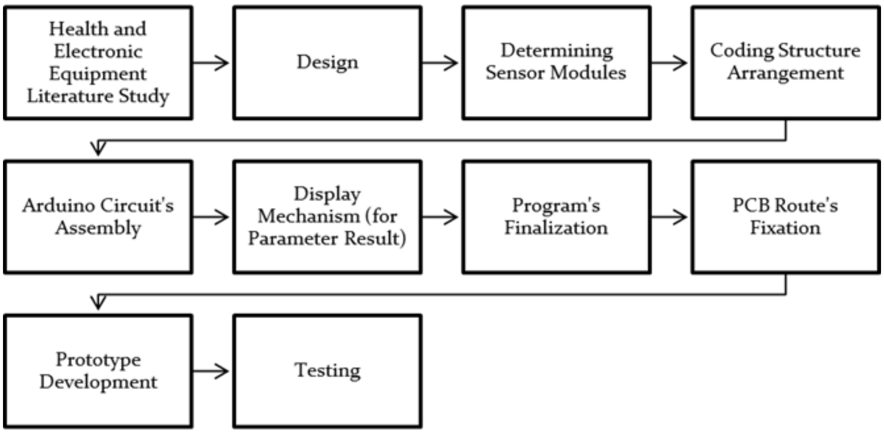

Figure 1. Low Cost PM3P Design and Prototype Development's Main Outline

The coding structure needed be arranged afterwards. The procedure then followed with assembly for electronic circuit on Arduino. And the later approach has to determine display mechanism for showing all the parameters' result. Program's finalization shall adjust the circuit's assembly on prior step. There did enter another phase to fixate the PCB route after being through the adjustment from Arduino electrical route and program's finalization too. The PM3P prototype development came through production flow to carry out testing which validates low cost PM3P towards industrial PM.

As for sensor modules, we prefer using MAX30100 sensor to gather heartrate and oxygen saturation data and DS18B20 lug type for body temperature. MAX30100 is opted as the sensor module because of its excellence which has capsule dimension and does apparently afford the data reading process from two parameters altogether. We literally opt DS18B20 as sensor module due to its resistance value, outcome response and plentiful availability too. And lug type is chosen as it presumably enables higher accuracy to read the body temperature data.

(a) (b)

Figure 2. Sensor Modules for Arduino Based PM3P (a) MAX30100 [9] (b) DS18B20 lug type [10]

On MAX30100 sensor, the power supply to Arduino attains 1,8 V. It will be allocated to two pins on Arduino that have role as serial communication line for this I2C sensor: SDA and SCL. The amount is respectively 0,4 V for output voltage and 1,4 V for input voltage. Another power supply allocation is intended only for red and infra-red components on LED with 3,3 V voltage supply. Each

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LED component has different wave length, 870 – 900 nm range for infra-red and 650 – 670 nm for the red one. Yet, MAX30100 has an 8-bit register. Bit 1 until 3 are unused. Bit 0 is to supply the current towards MAX30100. The remaining bits have the role to perform reading and calculation on all affordable parameters' data having been gathered: bit 4 for oxygen saturation; bit 5 for heartrate; bit 6 for body temperature; bit 7 for those all.

LED light -especially infra-red part- that being emitted by MAX30100 sensor can surely read any signal. The signal processing shall start once the received signal is clearly captured by wave length from both red yet infra-red components at LED. Then, the prior signal will be turned into digital signal by MAX30100's I2C module. In bit 6, digital signal can be converted into body temperature parameter result. Still, the outcome from conversion of digital signal at bit 7 will be heartrate and oxygen saturation parameters result.

The opening phase for PCB making began from an attempt optimizing use of circuit route as shown in Figure 3. below before proceeding the fixation for electrical route that will be printed on PCB. The procedure later entered completion for electrical route. The ongoing process obviously needed finalize the PCB electrical route. And eventually after completing all the design, production flow shall be fulfilled as the latter stage of PCB making.

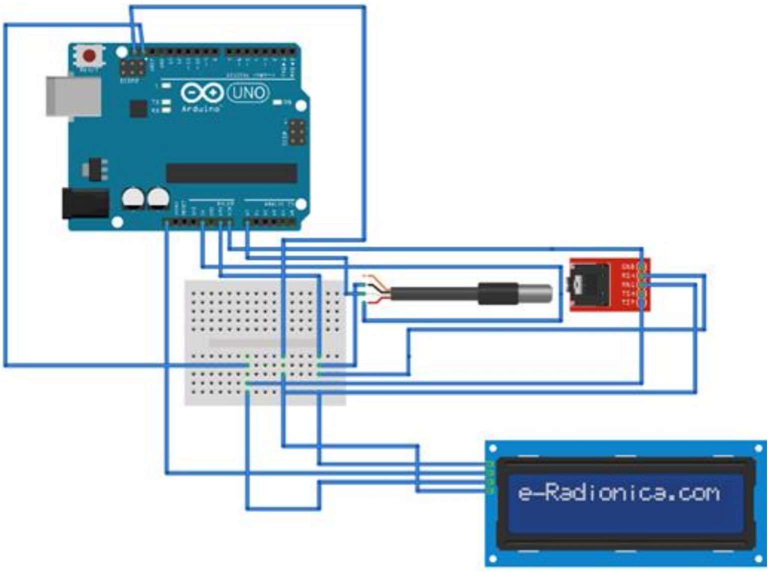

Figure 3. PM3P Arduino Schematic Electrical Route Design

3.1. Industrial PM (Healthcare Equipment Industry Patient Monitor)

Here, industrial PM is a Patient Monitor that does the reading process on each parameter with respective sensor which has become the standard provision in hospital. Every sensor can refer just for one parameter. And the data storing mechanism has already been integrated with particular software. PM industrial itself can actually measure five parameters such as followings: heartrate, oxygen saturation, body temperature, blood pressure and respiratory rate per minute. There, we chose the industrial PM as validator towards Arduino based low cost PM3P. Namely ECG 5 lead

3.2. Experimental Setup

Firstly, all the data was gathered from 10 adults. A data gathering takes a 5 minutes duration on one adult. And the sampling amount of each gathering reaches about 60 times, in which one sampling demands for 5 seconds. PM3P validation with industrial PM is being applied only for heartrate and oxygen saturation parameters. Rather, the calibration on DS18B20 sensor has already

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been done with responsible result [8]. And the PM3P Arduino validation result's finding method was performed by comparing sensor's reading error towards industrial PM. The validation scheme itself is illustrated through Figure 4.

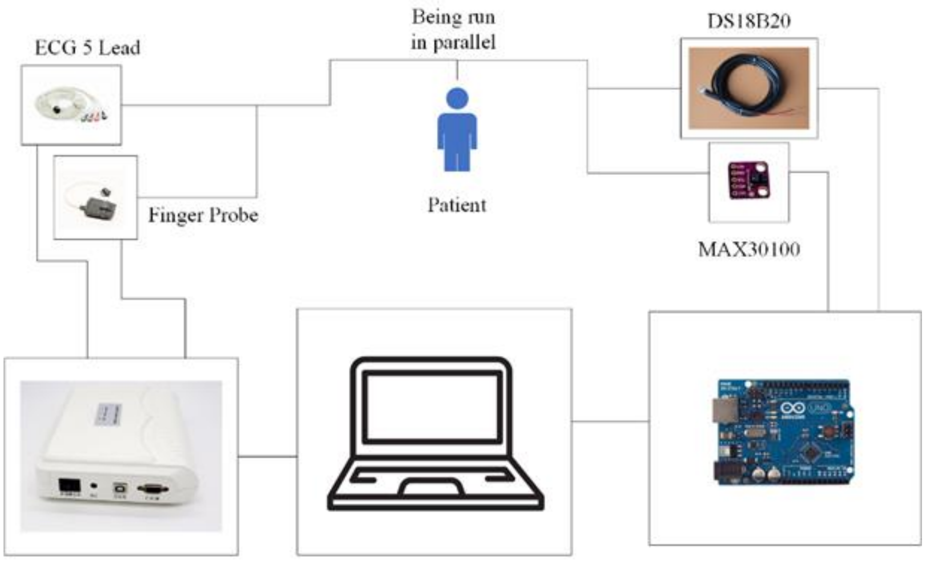

Figure 4. Low Cost PM3P Validation Scheme towards Industrial PM

3.3. Statistical Approach

PM3P error calculation was obtained through the difference value of PM3P and industrial PM -both heartrate and oxygen saturation parameters- per sampling. Then, the value was compared with the parameters result from industrial PM as the prime measurement reference. Equation (1) does literally define the prototype PM3P error percentage:

$$E_{PM3P} = \left| \frac{a_{PM3P} - a_{PMriil}}{a_{PMriil}} \right| \times 100\% \qquad (1)$$

Later on, acquired sampling on heartrate and oxygen saturation parameters from these ten adults would apparently be merged to obtain mean error. So all the acquired samplings need to be summed firstly, then the sum will be divided by the total sampling amount (N = 600). Thus, it is already interpreted with the following equation:

$$\overline{E_{PM3P}} = \frac{\sum_{i=1}^{N} E_{PM3Pi}}{N} \qquad (2)$$

4. Results and Discussion

The aim of making PCB is to compress all Arduino electrical circuit route in a series of cables by merging the design into a board. Another additional objective is to present result from all parameters on screen display. Thus, the PM3P prototype does truly practice efficiency yet affordable circuit cost as central approach of making PCB circuit route. The following is to adjust it with series of compiled program instructions being run in Arduino. So not only does the PM3P prototype outcome comprise MAX30100 and DS18B20 lug type sensor modules; but the LCD screen, as represented on Fig. 5.

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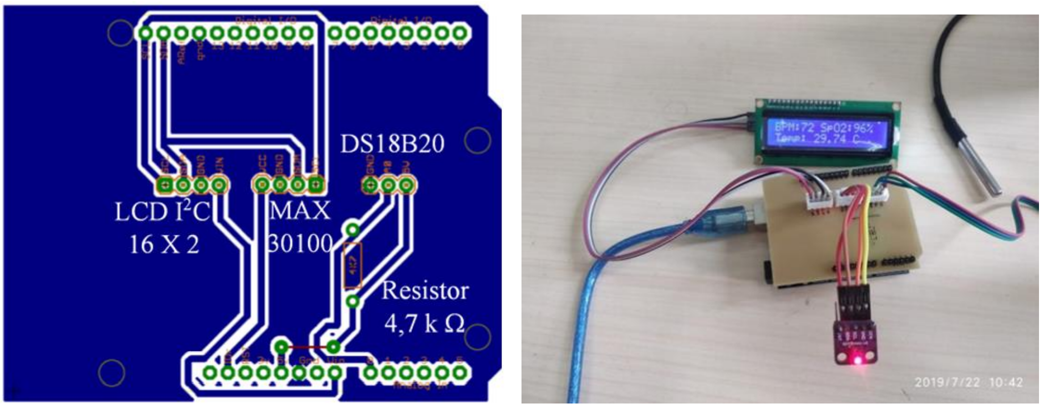
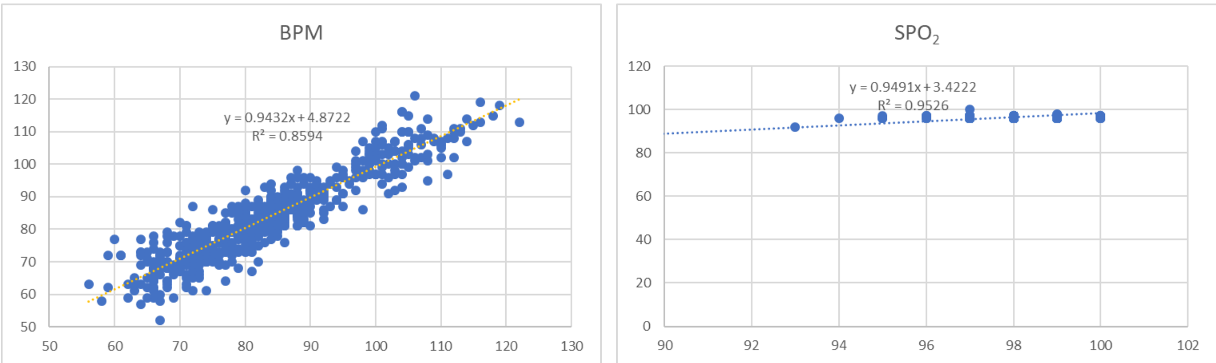


(a) (b)

Figure 5. PM3P Design and Prototyping Process (a) PCB Design (b) Prototype Outcome

Figure 5. fully explains every phase of Arduino based PM3P design and prototyping process. While designing the PCB, all electrical circuit route for both sensor and display modules is being merged using the schematic on Figure 3. as reference. Not to mention the design does have to adjust with Arduino size to enable the PCB be put on PM3P Arduino. Such design became main reference to enter PCB production work for PM3P Arduino. And this work's outcome completely replaced the previous electrical route that using breadboard and jumper cables.



(a) (b)

Figure 6. PM3P Reading Error towards Industrial PM (a) Heartrate Parameter (b) Oxygen Saturation Parameter

As for Figure 6., the graph represents acquired samplings' scatter from heart rate and oxygen saturation parameters result where the check intended to compare PM3P Arduino with industrial PM as validator on this experiment. On heartrate parameter, the scatter turns out to have a little broader spread since we often found the difference of reading process result between PM3P Arduino's MAX30100 sensor and industrial PM's ECG 5 lead.

The correlation is that MAX30100 sensor has slightly higher reading result than the validator itself ECG 5 lead for heartrate parameter. Conversely on oxygen saturation parameter, both PM3P Arduino (MAX30100) sensor and industrial PM's finger probe evidently have corresponding reading process result. Not to mention does the reading process truly deliver highly consistent yet precise result due to similar result. The proof also came from plenty of recurring samplings' oxygen saturation parameter result. Rarely does the difference result from industrial PM and PM3P Arduino exceed more than 3%.

According to the finished data processing, the result indicates quite slight error: respectively 0,31% for heartrate parameter and 1,59% for oxygen saturation. The error result is less than 2% in term of advisable error [3]. More, the leading cause of error difference from those two parameters is because of the sensor's data reading process stability. While there lies imbalance in result between MAX30100 on low cost PM3P and industrial PM sensor with considerable samplings on heartrate parameter, the reading imbalance nearly doesn't exist at all samplings on oxygen saturation parameter.

5. Conclusions

The validation's result already being discussed represents PM3P Arduino's performance in which it has relatively great reading accuracy. Even we needn't calibrate oxygen saturation parameter; only fit the result with finger probe on industrial PM referring to final error result. Further improvement aims for heartrate parameter calibration to enhance the reading accuracy on low cost PM3P Arduino. The Arduino based low cost PM3P's improvement will inescapably enter a series of improvement phases like clinical test and periodic production in the future.

Acknowledgments
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