JOJAPS

eISSN 2504-8457

Journal Online Jaringan Pengajian Seni Bina (JOJAPS)

Development of a NAO Robotics System Extension to Measure Heart Rate and Oxygen Saturation of Children

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Abstract

This project is mainly to assist paediatric based medical staffs when taking Heart rate and Oxygen Saturation measurements. The NAO humanoid robot will be used to assist the paediatric medical staff to enhance the current conventional measurement method. With the integration of the NAO robot, it will make the procedure to be more attractive and friendlier for children. By using the cute and human alike appearance, the NAO robot is capable to attract children attention and indirectly ease the whole process. In order to integrate additional sensors such as Pulse Oximeter sensor and Pressure sensor, the Arduino Mega microcontroller is used in this project. The data logging function also provided to the medical staff as an optional feature to save the measurement data. Finally, this project enables the NAO robot autonomously to perform the Heart rate and Oxygen Saturation measurement with minimal intervention from medical staff.

Key-word: - *NAO robot, Heart rate, Oxygen saturation, paediatric*

1. Introduction

This project generally focused to assist paediatric based medical staffs when taking heart rate and Oxygen saturation measurements. The current conventional measurement method for children is not children-friendly and sometimes they get frightened of the measurement equipment. Children also feel uncomfortable and do not give cooperation especially during their sick period. As a favourable solution for this problem, we proposed the NAO humanoid robot to assist the medical staff to enhance current methods in a more attractive way for children. NAO robot is capable to attract children attention with cute and human alike appearance. In addition, it also has some interactive features such as voice recognition and face recognition to communicate and ease the measurement process. The current conventional Heart rate and Oxygen saturation measurement method for children is similar to the adult measurement method. For some children, it seems not a child-friendly method and sometimes makes the children are afraid of the measurement equipment. Children also feel uncomfortable and do not give cooperation especially during their sick period. In order to enhance the current conventional measurement method, this project proposed the integration of the NAO robot for the measurement process. The involvement of the NAO robot in medical-based applications is not a disputable idea, especially in Human- Robot Interaction (HRI) concept [1]– [3]. There are few successful types of research involving the NAO robot in various medical fields such as Autism Syndrome Disorder(ASD)[4], children with Cerebral Palsy [5], Parkinson's Disease [6], and elderly care[7].

2. Preliminary study

In order to get inputs from people who are directly involved with children, a preliminary study was conducted using a questionnaire. The aims of the study also to get inputs from medical staff who have different levels of expertise such as a medical doctor, paediatric nurse, and assistant of the doctor. The questionnaire contains 10 multiple choice questions and statements with 5 points agreement scale. There is also one open end question that emphasizes any additional suggestions, preferences or requirements in order to improve the existing conventional method for Heart rate and Oxygen saturation of children. Figure 2 shows the bar chart which contains feedbacks from medical staff. In general, all the feedback on the usage of the NAO robot in medical-based applications seems very positive and encouraging. They strongly believe that this project could be helpful for medical staffs especially when performing the measurement process on children. Besides, they also strongly agree that the appearance of the robot able to gain a better co-operation from the children during the measurement process.

In order to obtain the trust of the children who see the robot for the first time, the medical staff hopes they will be some interactions between the robot and the child. This method can be smoothing the following measurement process and at the same time prevents any phobia or fear against the NAO robot among children.

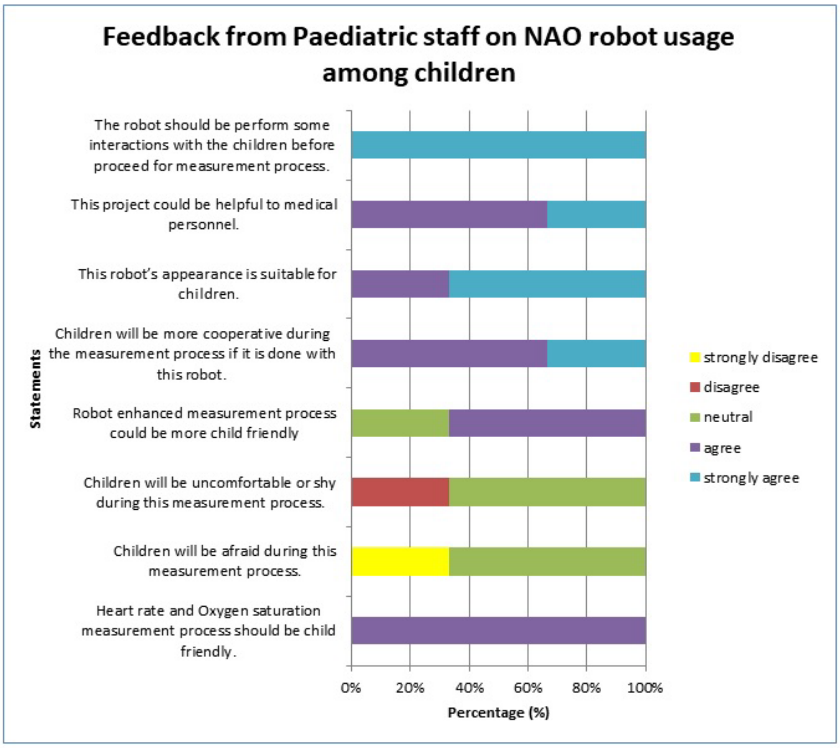


Figure 2: Feedback data from medical staff

3. **Objectives**

In general, this project proposes a solution to enhance current conventional procedures of the measurement of the Heart rate and Oxygen saturation. The NAO robot will be integrated with an additional medical sensor that can measure Heart rate and Oxygen saturation of children. Besides this sensor, a suitable pressure sensor also will be included to assist the measurement process especially to correctly hold the child finger without applying overpressure. This pressure sensor is one of the safety measures in order to ensure that the children finger not getting hurt or pain during the measurement process. A proper calibration method will be included for the sensor if required. Furthermore, a new sensor positioning adapter will be designed and developed to improve the sensor placement and accuracy of measurement without impairing the robot's movements. The project will be implemented and tested with children who are around the age of 3 to 12 years old. This implementation process also will be included by the medical staff.

4. **Background**

This project generally divided into two main elements, there are hardware and software. These two elements are integrated with each other in order to complete the whole system. The hardware elements consist of the NAO robot, Arduino Microcontroller and sensors. NAO is a humanoid robot equipped with sonar sensors, 2 CMOS cameras, and three fingered robotic hands. It features a multimedia system with 4 microphones and 2 hi-fi speakers for voice recognition and text-to-speech synthesis. The built-in features of this robot such as logo detection, mark detection using onboard cameras are loftily adjustable and are used for robot localization. The robotic hands are used for grasping and holding small objects. NAO can carry up to 300g using both hands. NAO Robocup Edition has 21 degrees of freedom (DOF) whereas NAO Academics Edition has 25 DOF since it is built with two hands with gripping abilities. For this study, the academic version of the NAO is used. The NAO is based on Linux and it is a fully programmable robot that uses its own framework called NAOQi. NAOQi, allows the developer to access all the features and functionalities of the robot through an Application Program Interface (API) which also provides the flexibility of executing tasks in sequential order, parallel and event-based. The Integrated wireless network card of this robot can be used to exchange information with other devices in the network.

The main key components as in figure 2.1 are:

• Body with 25 degrees of freedom (DOF) whose key elements are electric motors and actuators
• Sensor network, including 2 cameras, 4 microphones, sonar rangefinder, 2 IR emitters and receivers, 1 inertial board, 9 tactile
sensors, and 8 pressure sensors RR
• Various communication devices, including voice synthesizer, LED lights, and 2 high-fidelity speakers
• Intel ATOM 1,6ghz CPU (located in the head) that runs a Linux kernel and supports Aldebaran's proprietary middleware (NAOqi)
• Second CPU (located in the torso)
• 27,6-watt-hour battery that provides NAO with 1.5 or more hours of autonomy, depending on usage

In this project, NAO robot integrated with external microcontroller in order to process data from sensors. For this purpose, we selected the Arduino Mega 2560.This microcontroller board is based on the ATmega2560 [9]. It has 54 digital input/output pins (of which 15 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to DC adapter or battery to get started. The Arduino Mega is compatible with most shields designed for the Arduino Duemilanove or Diecimila. The Arduino Mega can be powered via the USB connection or with an external power supply. The board, also, can operate on an external supply of 6 to 20 volts. The ATmega2560 has 256 KB of flash memory for storing code, 8 KB of SRAM and 4KB of EEPROM. Each of the 54 digital pins on the Mega can be used as an input or output, using pinMode(), digitalWrite(), and digitalRead() functions. Adafruit's Data Logging Shield for Arduino makes it easy to store data on any FAT16-or FAT32-formatted SD card in such a way that most plotting, spreadsheet, or analytics programs can be read or retrieved later. [11]. The included real-time clock (RTC) timestamps all of our data with the current time, in order to helps us to refer the data based on date taken. SD card interface works with FAT16 or FAT32 formatted cards. Built in 3.3v level shifter circuitry lets us read or write super-fast and prevents damage to the SD card. The Real time clock (RTC) keeps the time going even when the Arduino is unplugged. The coin cell battery backup lasts approximately for 5 years.

There are various types of thin and flexible piezoresistive force sensors that were studied and evaluated for this project [12]. These sensors were single-contact point force sensors, and so were able to provide a single sensing pressure output based on the area of the applied load. The conductivity of these piezoresistive sensors rises with applied pressure due to increased contact between conductive particles in the polymer matrix of the sensor. The three sensors evaluated were the Interlink Electronics FSR 400 series, FlexiForce Pressure Sensor and Micro Force Sensor as in figure 4.1.

Figure 4.1: Evaluated sensors : (a) FSR 400 series, (b) Flexiforce and (c) Micro Force

Force Sensing Resistors (FSR) is a polymer thick film (PTF) device which exhibits a decrease in resistance with an increase in the force applied to the active surface [13]. Its force sensitivity is optimized for use in human touch control of electronic devices. FSRs are not a load cell or strain gauge, though they have similar properties. Interlink Electronics FSRTM 400 series is part of the single zone Force Sensing Resistor family. Force Sensing Resistors, or FSRs, are robust polymer thick film (PTF) devices that exhibit a decrease in resistance with increase in force applied to the surface of the sensor. This force sensitivity is optimized for use in human touch control of electronic devices such as automotive electronics, medical systems, and in industrial and robotics applications. Since the NAO robot does not have its own tactile sensor on its finger or palm area, some of the previous researches used this FlexiForce sensor [14]. Since the internal wiring on the NAO hand could void the manufacturer warranty, this sensor used for the tactile related processes such as detecting finger pressure and grasp an object [15]. The FlexiForce sensors can be used to measure both static and dynamic forces which can be up to 1000 lbs per square feet and thin enough to enable non-intrusive measurement [16].

The FlexiForce sensors use a resistive-based technology. The application of a force to the active sensing area of the sensor results in a change in the resistance of the sensing element in inverse proportion to the force applied. The FlexiForce sensor is an ultra-thin and flexible printed circuit, which can be easily integrated into most applications. With its paper-thin construction, flexibility and force measurement ability, the FlexiForce force sensor can measure force between almost any two surfaces and is durable enough to stand up to most environments. FlexiForce has better force sensing properties, linearity, hysteresis, drift, and temperature sensitivity than any other thin-film force sensors. The active sensing area is a 0.375" diameter circle at the end of the sensor. SingleTact is a single element tactile pressure sensor that accurately and reliably quantifies applied force combined with a simple interface board.It offers a 0 to 2V analog output for immediate Data Acquisition (DAQ) integration and an I2C based interface for integration into embedded systems. Standard and Calibrated sensors (with matched pre-calibrated interface board) are available[17]. For this project, we selected FSR 402 series pressure sensor due to its physical structure, flexibility, and accuracy of the reading. The Flexiforce sensor is not suitable to be placed in narrow sensor mounting. The Micro force sensor requires some additional wiring configuration to connect with Arduino.

Pulse Oximeter mainly used to detect Hypoxaemia which is the condition of abnormally low level of oxygen in the blood [18]. Pulse oximetry is the accepted standard for detecting Hypoxaemia. It was introduced in the 1980s and is now widely used in modern healthcare systems as a basic monitoring tool. It is simple, non- invasive technique and when used correctly, can provide reliable monitoring without distress to the patient. Using a probe placed on the finger, toe or ear lobe, the absorption of light (emitted by light emitting diodes (LEDs)) passing through tissue is measured and processed to produce a reading of pulse rate and oxygen saturation. The Hypoxaemia also can be detected through clinical signs and blood gas analysis. Clinical signs are often unreliable in the diagnosis of the presence or absence of Hypoxaemia. For example, cyanosis has poor sensitivity: the lack of cyanosis, despite severe significant central nervous system symptoms from hypoxaemia was recognised by J.S. Haldane in 1920. Blood gas analysis is expensive, invasive and provides a single measure in time only. Anaemia is a common condition in poorer parts of the world and makes the detection of cyanosis more difficult.

The fundamental principle behind Pulse oximetry is Photo-plethysmography (PPG)[20]. It is an optical technique that is used to measure blood volume changes in the tissue. The PPG waveforms for pulse oximetry are obtained by illuminating red and Infrared light(IR) through the fingertip of a person which are sensed by a photo detector. In this project we use reflective method that where IR, Red light and photodetector located in same side of finger. Only a small amount of light is detected while most of the light gets scattered and reflected by the skin and bones present in the path of light. Pulse oximetry is the non-invasive measurement of the oxygen saturation (SpO2). Oxygen saturation is defined as the measurement of the amount of oxygen dissolved in blood, based on the detection of Hemoglobin and Deoxyhemoglobin.(SpO2) is defined as the ratio of concentration of Oxygenated hemoglobin to the total hemoglobin concentration present in blood as in equation below

$$\%SpO_2 = \frac{C_{hbo}}{C_{hbo} + C_{hb}}(100)$$

Chbo = hemoglobin concentration
Chb = Deoxygenated hemoglobin concentration

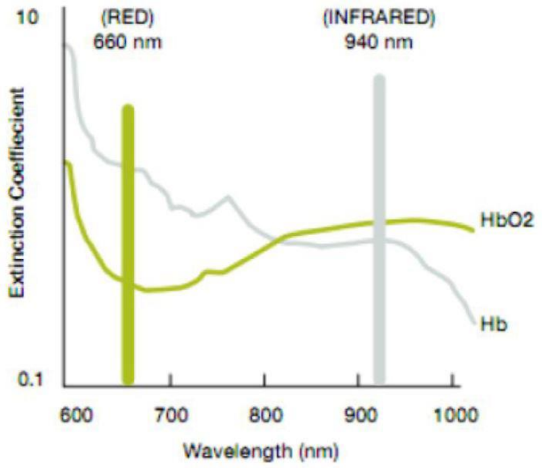
The bloodstream is affected by the concentration of (HbO2) and Hb, and their absorption coefficients are measured using two wavelengths 660 nm (red light spectra) and 940 nm (infrared light spectra). Deoxygenated and Oxygenated hemoglobin absorb different wavelengths. Deoxygenated hemoglobin (Hb) has a higher absorption at 660 nm and (HbO2) has a higher absorption at 940nm.In other word, oxygenated hemoglobin absorbs more infrared light while deoxygenated hemoglobin absorbs more red light.For measurement of (SpO2), using the DC and AC parts of the IR and Red signals, the ratio(R) of ratios is calculated as

$$R = \frac{\frac{AC}{DC}RED}{\frac{AC}{DC}IR}$$

The formula relating R to oxygen saturation measured by Pulse oximetry, is then determined by proposing a mathematical relationship, given by:

$$SpO_2 = A - B * R$$

where A and B are coefficients obtained by means of calibration. According to Beer Lambert Law, the amount of absorbance when light is passed through a substance is directly proportional to the thickness and concentration of that substance [20].



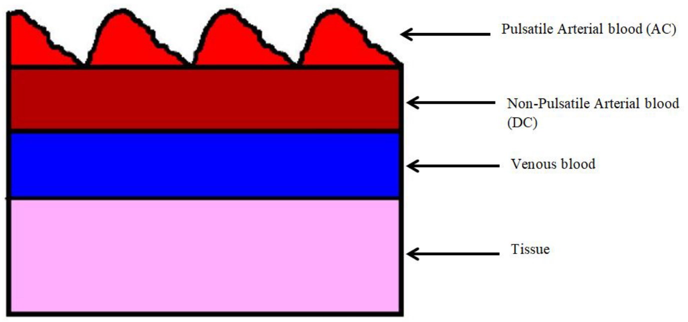
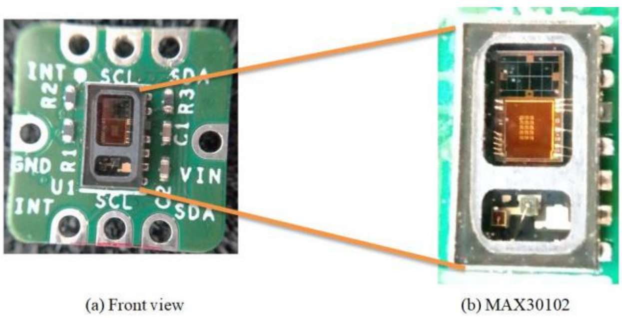


Figure 4.2: Hemoglobin light absorption graph Figure **Figure 4.3:** Light absorption diagram

A photodetector in the sensor perceives the non-absorbed light from the LEDs. This signal is inverted using an inverting operational amplifier (OpAmp) and the result is a signal like the one in figure 4.3. This signal represents the light that has been absorbed by the finger and is divided in a DC component and an AC component. The DC component represents the light absorption of the tissue, venous blood, and non-pulsatile arterial blood. The AC component represents the pulsatile arterial blood. For the Pulse Oximeter sensor, we selected The Maxim MAXREFDES117 as in figure 4.4 from Maxim Integrated Inc. The sensor has an integrated pulse oximetry and heart rate monitor module and operate based on LED Reflective method. Mainly it consists of sensor module MAX30102, Step-Down DC-DC Converter module MAX1921 and Logic-Level Translator MAX14595. It includes internal LEDs, photodetectors optical elements, and low-noise electronics with ambient light rejection. It operates on a single 1.8V power supply and a separate 3.3V power supply for the internal LEDs. For the Communication is through a standard I2C-compatible interface. Besides, module can be shut down through software with zero standby current, allowing the power rails to remain powered at all times. This device provides a complete system solution to ease the design-in process for mobile and wearable devices such as Fitness Assistant Devices, Smartphones and Tablets. The MAX30102 is a complete pulse oximetry and heart-rate sensor system solution module designed for the demanding requirements of wearable devices. The device maintains a very small solution size without sacrificing optical or electrical performance. Minimal external hardware components are required for integration into a wearable system. The MAX30102 is fully adjustable through software registers, and the digital output data can be stored in a 32-deep FIFO within the IC. The FIFO allows the MAX30102 to be connected to a microcontroller or processor on a shared bus, where the data is not being read continuously from the MAX30102's registers. Since the MAX30102 already contains its own build in Digital filter, for this project we additionally use Moving Average Filter to obtain correct reading from the sensor. The moving average filter smooths by computing the arithmetic average of some number,N of consecutive input values such as Heart rate and Oxygen saturation values.



(a) Front view (b) MAX30102

Figure 4.4: Front Construction of Maxim MAXREFDES117

For the development programming algorithm and design sensor mounting, mainly 3 software were used. Choregraphe is the programming software that will allow NAO users to edit and create movements in a simple user interface (UI) [24]. The user can create a series of behaviours by dragging and dropping the predefined behaviors from the library, NAOqi. These behaviour boxes are easily configurable allowing a user to develop a new movement not currently held in the library. In the application, the user can view the robot's position as they are giving him each movement.

They can choose to connect to a NAO robot or to connect to a NAO simulation robot. If the user is using a NAO robot, the video feed of the robot can also be seen in the application. This application was used in our development to understand the behaviour and interfaces of the NAO robot as well as learning to see how the movements were sent to the robot. Figure 2.21 is an example screenshot from the Choregraphe application [8].

The Arduino is an open-source prototyping platform [26]. A prototype is a first step in producing a new product, allowing for proof-of-concept testing that could lead to possible future refinement and production. The language that we will use to code the Arduino is a high-level computer programming language called processing or wiring. It is a slight adaptation of the very popular programming language C++, which has been around for quite some time and is in widespread use in industry. C++ and its predecessor C are very powerful computer languages and were even used to write sections of the Microsoft Windows operating systems. Microcontrollers in the past, such as the 8-bit Motorola (now Freescale) 65HC11, used a low-level programming method of operational codes (opcodes), with specified addresses that were entered through the use of hexadecimal numbers, which are one step up from the binary one and zero machine language. CATIA stands for Computer Aided Three-dimensional Interactive Application. It's a commercial CAD software used for physical modelling in various industries including Mechanical and Aerospace. It was developed by Dassault Systems in the early '80s mainly for the aerospace industry.

5. **Framework & implementation**

The project framework consists of designing and evaluation of the mountings for hardware, developing project algorithm and integrating software and hardware. The main focus of project is to obtain a correct reading from the pressure sensor, Pulse Oximeter, and Arduino, suitable hardware mounting is very important for this project. Each of the hardware mountings evaluated with the different design concepts and utilization approach. For the designing purpose, CATIA version V5R19 was used. The CATIA is able to convert a 3D design into the "STL" (Standard triangle Language) file, then it could be opened in 3D printer's software, "Cura 3.3". The 3D printer use material type PLA. In order to match the NAO robot body colour, we used PLA type material in white and silver colour, with a temperature range between 195°C to 205°C.

Based on the project algorithm, the Pressure Sensor and Pulse Oximeter are interrelated to each other in the measurement process. Thus, there are few mounting designs evaluated based on its suitability to fit on NAO robot fingers. While assisting to provide accurate sensor reading, this mounting should not be obstructing any standard movement of NAO robot such as Sit down or Stand-up position. If any obstruction happens during movement robot, it could lead damage to sensors or damage to the robot especially fingers. Besides, the sensor mounting should be lighter in terms of weight to prevent any excess workload to the robot's arm. If the sensor mounting is heavy, it could increase the temperature of the robot's arm motors. In addition, the extra workload could also affect the stability of the robot especially when walking. The overall configurations shown as in figure 5.0. This project uses two algorithms to complete the Pulse Oximeter measurement process. Both of the algorithms interrelated and communicate with each other in order to obtain measurement reading. For the Arduino, we used Arduino Mega R3 because it has some advantages compared to previously used Arduino UNO. Since we integrating pressure sensors, Pulse Oximeter sensor and Data logging shield in this project, the Arduino Uno unable to support in terms of dynamic memory for data. Its global variables use a 134% dynamic memory of Arduino and generating an error during the compilation process. As an alternative solution, Arduino Mega R3 is selected due to its capability to cope with data from sensors and Data logging shield. It only uses 38% of the dynamic memory for the global variables during the measurement process.

The Choregraphe algorithm focused on an autonomous concept that allows the NAO robot able to execute the measurement process with minimal assists from medical staff. The medical staff only needs to control the whole process with 3 tactile buttons located on the NAO robot head. Before executing the measurement procedure of Heart rate and Oxygen saturation, the NAO robot will use the NAO mark ID to verify the access of medical staff. If the staff failed to provide correct verification, the robot would not stand up and tracking the NAO mark. Alternatively, it will proceed to remain in the rest position. This NAO mark recognition system is act as a safety measures that ensure only the authorized person is handling the NAO robot. In addition, this measure could also prevent any damage to the robot or injury to children due to improper handling of the robot. Additionally, there are also other safety measures included in this algorithm which allows the medical staff to terminates the robot's movement immediately by pressing any of the leg bumper sensors in the event of an emergency. The robot will immediately switch to rest posture and release its motor stiffness. The bumper sensor can stop the robot when colliding with any obstacles during the tracking process.

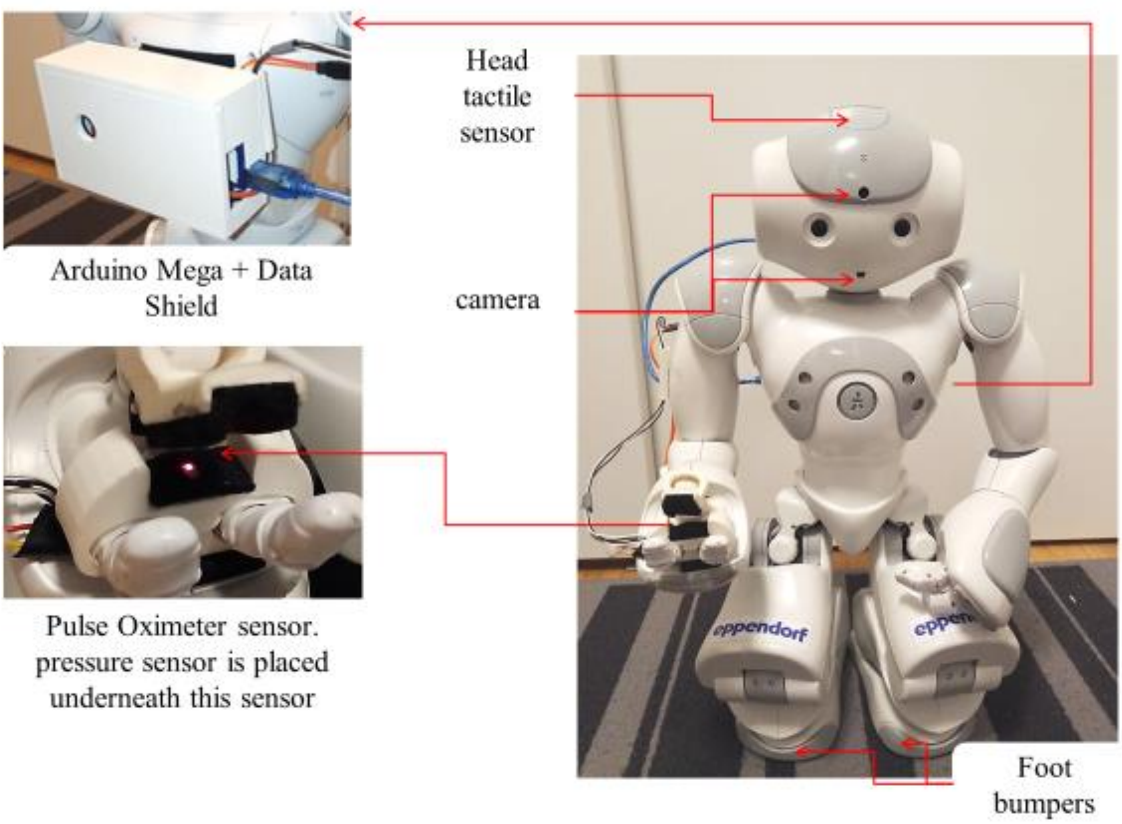


Figure 5.0: sensor and hardware configurations

For the integration between Arduino and Choregraphe, the ArduiNAO library is used. But, this additional library has certain compatibility issues such as it would not compatible with older version of Arduino Mega boards (R1 or R2). It only compatible and working well with the Arduino Mega R3 or any newer board. In this project, Arduino and Chroregraphe communicate through serial communication. The Choregraphe able to send data and read data. Through this capability, the Choregraphe able to select the sequence of process in Arduino. It even can reflash the Arduino through the ArduiNAO library. In general, the overall conceptual architecture between sensors,Arduino Mega, SD shield and robot are as in figure 5.1

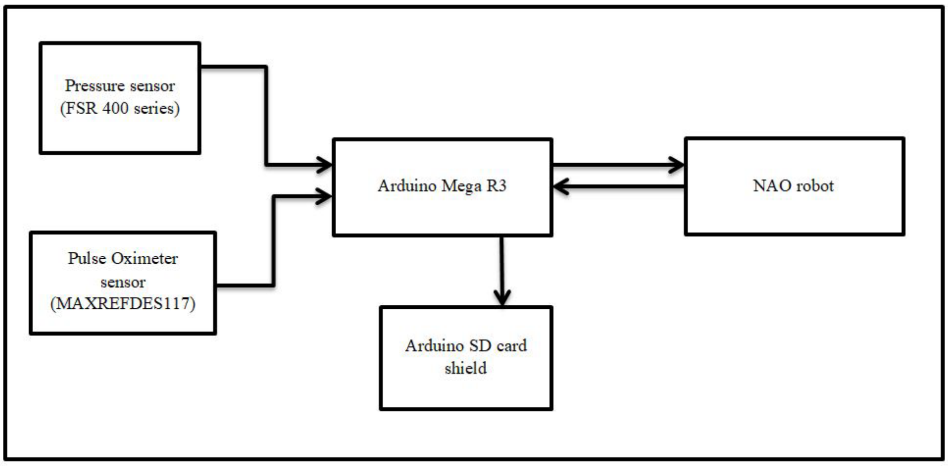


Figure 5.1: conceptual architecture representation between hardware

6. **Evaluation & result**

In this project, the placement of finger throughout the measurement process is a crucial factor to obtain an accurate reading. The finger firmly pressed on the glass surface of the Pulse Oximeter sensor. But humans are generally bad at applying constant pressure to a thing. This could be worse among children who are not physically strong enough to apply constant pressure on the sensor. In order to overcome this problem, we design the project as the NAO robot hold the children finger at a certain range of applied pressure without hurting their fingers. To ensure the correct range and adequate pressure is applied on different size of children, we set a threshold about 1 Newton on pressure which applied by the NAO robot during the measurement process. We tested applied pressure based on percentage of robot's fingers opening which varied from 0 to 100%. In this project, we tested on finger diameter size of 1.5cm and 1.0cm.

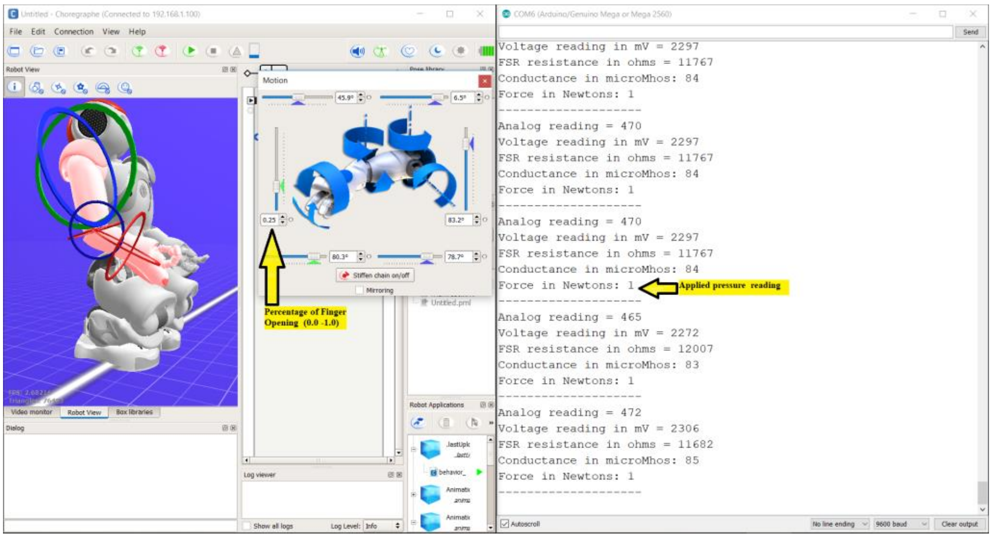


Figure 6.0: Medium level grip with 25% of NAO robot finger opening

First, the NAO robot will grip the finger to check the amount of the applied pressure. The amount of applied pressure is identified based on the analog output from the pressure sensor. We set about 1N pressure as a threshold to get adequate and correct range applied on Pulse Oximeter sensor. If the applied pressure is lesser than 1 N, then the robot will tighten the grip to 15% of finger opening. If the initially applied pressure is sufficient and adequate as required by the sensor, then the robot will remain in medium grip at 25% of finger opening. For the case such as the invalid measurement reading, the robot will recheck the grip level and proceed to the Heart rate and Oxygen saturation measurement.According to the autonomous concept, the robot should independently detect the person who is going to be measured. For this purpose, in this project, we used two types of trackers which are NAO mark tracker and red colour object tracker as in figure 6.1

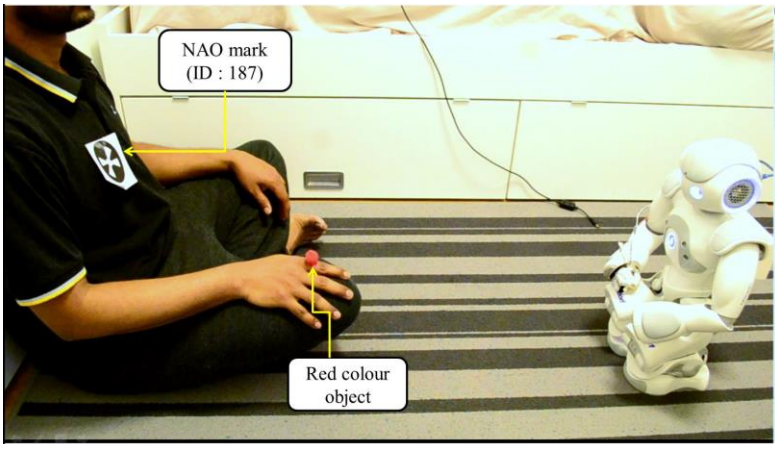


Figure 6.1: Application of the tracking system

The NAO mark also used for access verification to identify authorized personnel who can handle the robot. The radius NAO mark is used as a reference to make the NAO robot walk towards the direction of the child. After the NAO reached to the middle of the target distance, it will switch to a red colour object tracker in order to identify the exact location of the finger. The NAO robot will stop at a safe distance and the robot will align its right arm position in a straight line to the child finger. For this robot move a few steps to the left direction. After that it will be crouched to grip the finger.

The measurement process of Pulse Oximeter tested with 2 possible conditions. Firstly, the measurement reading is correctly obtained and it is within the valid region. Secondly, we tested with some error conditions such as intentionally does not place the finger properly on the sensor. By this, we checked whether the robot able to differentiate between valid and invalid measurement data. As a result, the robot managed to identify the invalid measurement data and rechecked the grip level and proceed the Heart rate and Oxygen saturation measurement process to obtain correct data. In order to verify the accuracy of project result, we simultaneously tested the Pulse Oximeter sensor with a commercial Choice Med MD300-D Finger Pulse Oximeter. This portable Pulse Oximeter has accuracy of ±2% for Oxygen saturation reading and ±2bpm for Heart rate reading. The figures below shows comparison between the 2 resources.

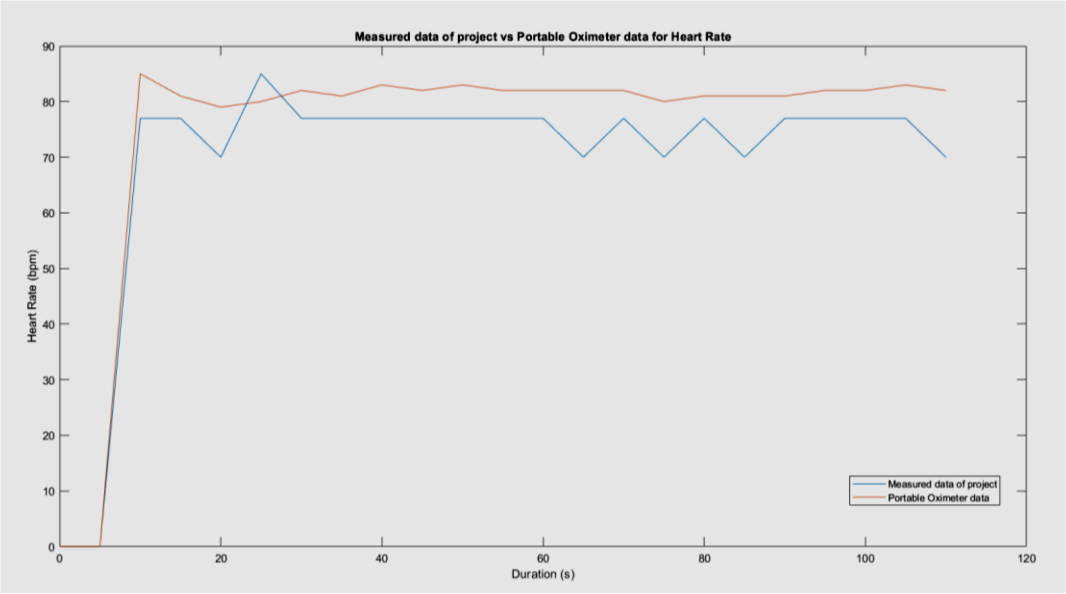


Figure 6.0: Comparison between measured data of project and Portable Oximeter data for Heart Rate

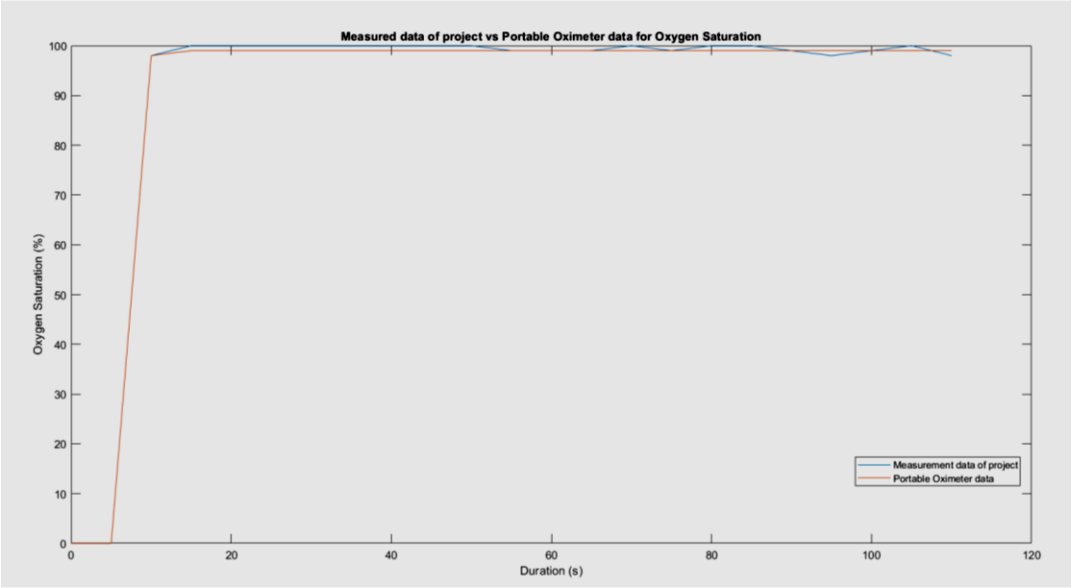


Figure 6.1: Comparison between measured data of project and Portable Oximeter data for Oxygen Saturation

7. Conclusion

This project managed to develop a NAO robotics system extension to measure the Heart rate and Oxygen saturation of children. The robot able to performs the measurement task autonomously with minimal intervention from the medical staff. The results highlight the significant promise and potential of the NAO robot to be used in medical related task especially which involved children. All the sensor used in this project was evaluated based on the physical suitability and accuracy of the reading. There are some safety features added into this project such as collision detection through the bumper sensor, emergency stop and access verification for authorized personnel. These measures will ensure no children get injured during the improper measurement procedure and also to prevents the robot from getting damaged during a collision. In order to respect the privacy of children and adhere to legal boundaries, the measurement data saving method given as an optional function.

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