Pain Assessment: A Proof of Concept for the Correlation of Sensor-based Physiological Readings to Self-Report Methods

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***Abstract*—Pain can cause emotional effects on human-like anger, depression, mood swings, and irritability. The discomfort caused by pain can only be seen, but the level of the pain is only felt by the person enduring the pain. One method used by clinicians and doctors to identify one's pain level is the use of pain score to rate the level of pain endured. Three ways are available to rate the level of pain, which are the patient's self-report method, behavioral measurement, and physiological measurement. This study focuses on the correlation between two methods, which are physiological measurement and the self-report method. The hybrid of integrated physiological sensors and self-report mobile applications is used for system testing in this study. Three physiological variables were used to be collected in system testing which are the heart rate, body temperature, and Galvanic Skin Response. While for the self-report, an Android mobile application was used to capture the pain level experienced by the authors in the form of numerical scale. To find the correlation between them, all the data collected from the system testing were analyzed using Pearson correlation coefficient formula. The results of the correlation suggested that the heart rate and GSR has a positive relationship with the self-report, while body temperature has a non-correlated hypothesis. For further work, medical science people and clearance from human ethics need to be considered in the assessment.**

***Index Terms*—Correlation between Self-Report and Physiological Measurements; Pain Score; Physiological Measurement; Self-Report.**

I. Introduction

Pain is a fundamental feeling that builds the ability in humans to avoid dangerous hazard. Since the level of pain is unseen, pain measurement or pain scoring method has been initiated to rate one's pain endurance level. Pain score refers to a method used to scale and to communicate the pain severity endured by a patient. Several types of pain score scales have been proposed to assess the severity of pain. These tools have been evolved from assessing the threshold and tolerance determinations of pain intensity, in which the assessment of pain severity is done by using psychological and physiological methods [1-3]. Despite of the many types of pain score methods, they all share a common goal, which is to portray human pain experience accurately from the patient's perspective. Studies in clinical analgesic have employed the category rating method by choosing a word from a category list of words (e.g. none, moderate, severe, and very severe) [4]. Other methods used to score pain include scaling by number or choosing a facial picture. In this method, the more the pain endured by one, the higher the pain score level he/she should mark on the scale. Assessing pain is essential in pain diagnosis as what one may describe the pain as severe may only be mild to another [3]. Self-report, which is one of the common tools used to assess pain is carried out by requesting patients to draw or choose their level of pain based on a provided scale. Although the scale may comprise either numbers, faces or graduated lines of color, the most common self-report tools is the Numerical Rating Scale (NRS), which uses a scale with the numbers from 0 to 10. Based on [5], healthcare professionals only require a little training to use the tools in clinical practice, which means that these tools and method of pain assessment is easy to use. The author of [5] the mentioned research found that self-report is a success because some studies have found that the tools are accurate in measuring both acute and chronic pediatric pain at different ages in childhood.

Physiological measurement assesses how well a patient's body functions. It involves assessment of patient's heart rate, respiratory rate, blood pressure, oxygen saturation, and body temperature. An Increase or a decrease in heart rate, shift in respiratory and breathing patterns, fluctuating body temperature, blood pressure and saturation of oxygen are integral in physiological measurement for scoring pain. Changes in the measurement dictate the severity of pain endured by a patient. This method helps to validate an experiment linked with pain. The measurement serves as evidence from the past pain reports associated to stimulus [1]. The measurement outcomes can be used in hypothesis testing for future experiment or study. Physiological measurement is beneficial in quantifying the aspects of human pain experience, which has been mostly disregarded in recent research studies [1]. Although behavioral observation is another way of detecting pain, in certain circumstances, physiological measurement is useful to measure pain. These tools can overcome obstacles in behavioral observation and assessment of pain in infants and young children. This population of patients is unable to express their pain experience. One disadvantage of the behavioral measurement is the confusion that may arise when taking the pain measurement; if the results taken are from the severity dimension of pain and pain affect, or merely a reaction to distress [6]. Self-report and behavioral measurement have been criticized as both methods focus on the muscular activity of patients, instead of detecting pain, due to their measurements of muscular reflex [7]. Figure 1 illustrates an instance of scale used by observing the behavioral aspect of a patient.

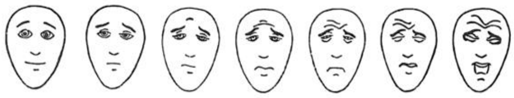

Figure 1: Faces pain scale from none to severe pain (Daiva et al., 1990)

The present pain scales (e.g. Verbal rating scale (VRS), Visual analog scale (VAS), Numerical rating scale (NRS), Picture or Face scales, Descriptor Differential Scale of Pain Intensity, and Behavioral Measurements [3]), are measured by comparing a patient's self-reported pain scores with the output of novel device [7]. In behavioral measurement, facial recognition system is integrated by using a camera to detect patient's facial expression, but it cannot identify the precise and accurate pain endured by non-communicative critically ill adults [8] [9].

Although self-report is the gold standard in pain scoring, the author of the paper [7] suggested for getting pain scoring by taking a physiological measurement (heart rate, respiratory rate, and body temperature) [7]. The correlation between the two methods is needed because physiological markers cannot correlate directly with pain [10]. Thus, this research generated a pain score scaling correlated between self-report and physiologic markers [7]. A wearable sensor fusion device to monitor the physiological variables in the medical field [11] and a pain self-report application had been implemented [12][13], but none had correlated the implementation of self-report and physiological markers. Hence, we proposed a hybrid between the two methods by using sensor fusion and Android mobile application. Our work aimed to find the correlation result between the two assessment methods.

II. Material and Method

Pain is subjective as pain can only be experienced by an individual. Pain assessment refers to a clinical judgment method that measures pain endured by patients. It is more significant to measure pain intensity than to reckon the presence of pain. There are many advantages of the developed pain assessment tools. One is that it helps a clinician to choose the most appropriate therapeutic procedure and to assess the effectiveness of a therapy. Second, using pain measurement tools reduces the time taken for the staff to assess patients' pain. Besides, these tools have been designed to obtain complete information about a patient's pain experience. The best way to determine the severity of one's pain is by communicating with them. Severe pain becomes the primary focus of a person, as every activity comes to a halt automatically due to the discomfort caused by the pain.

A. Pain Assessment

The conventional way of assessing the subjective nature of pain is by relying on the solely subjective report, which may raise doubts as there is no meaningful way to measure pain. The basis of conventional method in assessing pain is by asking patients about the pain they feel. The unstructured communication between patients and doctors may lead to poor results. This problem can be solved by using standardized questions. Thus, pain measurement scales have been designed and introduced to clinical, and it appears to be the most widely used pain measurement tools by both the academics and clinicians. Advanced technologies in clinic facilitate the transfer of medical information and yield immediate scores that are available for clinical and research purposes [14]. However, these methods do not enhance the process of pain assessment purpose, which relies on the psychometric properties of the questions posed to the patients.

Pain is judged based on observation of the type, significance, and context of one's pain experience. The three ways to assess pain are by observing the behavior of the patient, observing the vital signs or physiological function of the patient, and patient self-report. These tools have been introduced in recent studies, either unidimensional or multidimensional, which is a combination of behavioral and physiological aspects [1]. Among the three methods, self-report seems to provide the most accurate and reliable information [7].

Many studies have looked into pain assessment in neonatal and infants, children, and elderly. This is because the approach of pain assessment in elderly differs from that in the younger population, including gender variation [15]. Since pain is common amongst elderly patients, assessing pain in this population is indeed challenging [6][14]. The VAS is the easiest tool for the elderly to assess their pain by choosing categories of words to describe their pain level. This measurement is suitable for the elderly to describe their pain, instead of converting their pain feeling to a number, facial representation or pointing somewhere on the line. Based on [16], VAS is creating a bias in favor of treatment, as the scale does not afford patients the opportunity to record an increase in pain. Some research shows that the use of VAS results in a higher failure of completion rates than the use of NRS for elderly patients [17][18]. For this reason, VAS was not considered in this study.

Many studies have assessed children [9][10][19][20] using the behavioral method to overcome the problem in measuring pain report arising from the children's limited cognitive and language skills. Since infants cannot verbalise their pain, the behavioral method is effective to assess their level of pain. Many studies have used the behavioral method to assess pain in neonates [1][21][22].

B. Self-Report

Pain is subjective, and the best assessment is the self-report method [23]. Recent studies seemed to rely on pain self-report method due to absence of valid and reliable technique to measure one's experience of pain [24]. In the self-report method, patients translate the pain they feel into words, and this method has been widely used in children of 5 years and older [9]. This method cannot be used to assess pain in infants and neonatal due to their inability to communicate. Pain assessment via behavioral method is useful and more effective when compared with self-report. This tool is recommended for children aged between 3 and 4. The self-report method is also intricate for patients with communication impairment.

Self-report pain scale is the tools used by the clinicians to allow patients to scale their level of pain. This method recognizes that the individual is capable to determine the level of pain he/she suffers. A self-report pain scale is the best tool to answer, "how much does it hurt?". In other words, it can measure the intensity of pain [25]. Pain Intensity should be assessed using unidimensional scales based on the self-report method [14]. The use of unidimensional pain scales, such as the abovementioned three tools, is recommended to assess pain intensity [14]. Advanced technology is not required for such self-report technique [26]. The techniques for the three self-report tools are almost similar, wherein a study that compared VRS and VAS [27] displayed insignificant variance. The validity and reliability of these three scales have been tested in [28] empirically by placing focus on pruritus.

1) Visual Analogue Scale (VAS)

The VAS refers to a horizontal scale of marking that indicates the level of pain intensity with each end labeled as the extremes of pain – 'no pain' to 'worst pain'. Figure 2 illustrates that the way VAS was used to score the level of pruritus was similar with the way it was employed to determine the level of pain intensity [28]. The VAS tool usually is a ruler with a red line on the side. The red line can be moved by the patient on one side of the ruler and scored by the nurse on the other side. This tool has some advantages as pain can be measured continuously. The VAS requires adequate levels of visual acuity, motor function, and cognitive ability to translate pain into a distance measure [29]. This scale has the potential to offer the greatest opportunities for discrimination [14]. Marc et al., [4] asserted that the subject should have more variables to accurately judge the pain.

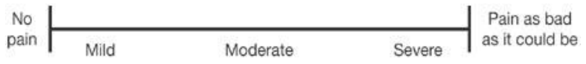

Figure 2: Visual Analogue Scale (VAS)

2) Verbal Rating Scale (VRS)

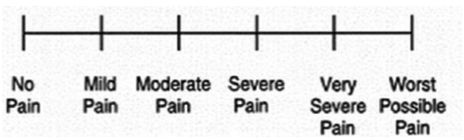

Figure 3: Verbal Rating Scale (VRS)

Although VRS has been widely used, this tool has some disadvantages, when compared to VAS [27]. The VRS is composed of 5 to 7-word categories (e.g. no, mild, moderate, severe, unimaginable pain). Although these words can be changed as they do not affect the assessment process, the scale must be arranged by the level of pain severity. For example, the far left indicates the lowest level of pain intensity, while the far right reflects the highest level of pain. Author from paper [30] has suggested that NRS is more preferable compared to VRS as VRS causes the difficulty in distinguishing and ordering high number of verbal descriptors, while 0-10 NRS has a greater sensitivity.

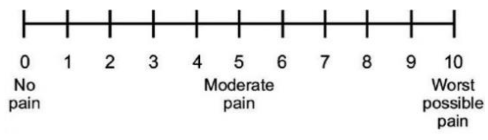

Figure 4: Numerical Rating Scale (NRS)

The NRS has score levels ranging from 0 to 10 or 0 to 100. Patients are asked to indicate the pain intensity by reporting a number that best represents it. The far right of the scale indicates the highest-level degree of pain. This tool is often used by clinics to measure pain [29]. This tool is more practical, when compared to VAS, and easier to understand for most people [13]. A study [14] that focused on people with lower education showed that it was difficult for them to assess pain via numeric scales.

C. Behavioural Measurement

One method used to assess patient's pain experience is by observing the changes in facial expression of patients [20]. Eyes, mouth, frown line on the brow, chin, and tears are the main parts to measure the level of pain amongst patients. Observing changes in patients' facial expressions has been a widely used method in several recent researches [26][31][32], despite of other available variables that can be measured, such as activities (moving in bed) and activity diaries [32] that measures the amount of time spent standing, sitting or reclining, sleep patterns, sexual activity, performance on specified tasks (movement of joint), medication demand or intake, food intake, normal household activities (meal preparation and gardening), and recreational activities.

A review of assessing pain in patients with communication impairment was conducted in a recent paper [31] after looking into patients with language problems, patients in the extreme of age, and patients who were critically ill in intensive care setting. Pain reactions and behaviors were the indicators monitored to indicate one's suffering and painful experiences. Face-Legs-Activity-Cry-Consolability was used in [31] to validate the scoring postoperative pain in infants and children, age ranging between 2 months and 7 years. The CRIES Pain Scale was also used in [21] to assess pain amongst neonates or new-born baby. It did not only apply scores from 0 to 2, but it was also combined with the physiological measurement for pain scale. The MOBID Pain Scale was used to assess pain amidst the elderly with dementia by monitoring their behavior.

Another study observed pain in unconscious or sedated patients who cannot communicate using Numeric Pain Rating to scale their level of pain [8]. Although face expression has been widely used by many researchers to identify the level of pain intensity, no precise and accurate method is available to interpret facial expressions of pain in non-communicative critically ill adults [8]. Hence, this method needs to correlate with a self-report method to generate accurate outputs. Such assessment, however, requires technical training to ensure standardized measurement and to avoid this from turning into a burden, as there are simpler instruments to assess pain.

D. Physiological Measurement

In pain management, a physiologic marker of pain has been a part of many studies. Some physiologic variables or vital signs commonly used by researchers to measure pain severity are skin conductance [22][24], heart rate [10][15][24], respiration rate, cortisol levels, palmar sweat, and endorphins [10]. "A physiological event can be correlated with pain if the event co-varies with the pain report in a dataset" [32]. This statement strongly supports the use of physiological reading in assessing pain. The purpose of correlating pain score and physiological reading is to confirm the validity of the experiment by offering supporting evidence. It also provides additional information to be used in hypothesis testing and in quantifying aspects of the human pain experience [32]. This is because painful stimulus generates many physiological changes [15].

In studies related to pain management in neonate [21], physiological measurement offers more accurate description of pain. This proves that integrating physiological markers helps in obtaining accurate information of pain. Besides, the reading of vital signs for pain measurement may allow distinguishing the level of pain. The pain studies on infants would look into the number of beats per unit of heart rate, wherein increment in heart beat indicates stressful or painful stimulus endured by infants [10]. Mcgrath [10] has conducted a study in measuring pain on neonatal, thus dismissing the self-report method to score pain. The study noted changes in vital signs when the infants/neonatal responded to painful stimulus.

The research relied on behavioral method and embedded vital signs of the neonatal, which represented a correlation of the two pain assessment methods. 22 infants, whose age ranged from 32 to 60 weeks, were assessed hourly with the period of assessment ranging between 24 and 72 hours. The period of assessment depended on the severity of surgical procedure. The vital signs incorporated in the study were blood pressure and heart rate. Three levels of numerical score were applied in the study [21], which is from 0 to 3 with 0 described as no pain at all [24]. If both heart rate and blood pressure were unchanged, the pain score for the infant was 0. If the heart rate or the blood pressure increased without exceeding 20%, the level of pain was scaled to 1. If either one of the two increased and exceeded 20%, the pain level was scaled to the highest. Changes in vital signs can be an early sign of the presence of pain. Acute pain is accompanied by neurohumoral responses, and it can lead to changes in heart rate, blood pressure, and respiratory rate [33]. Physiological measurement is a limited value for pain scoring [9]. This method has to be used in combination with subjective reports or self-reported by patients, unless a highly reliable physiological measure unique to pain is avail.

E. Sensors Integration in Previous Pain Assessment Research

The previous review focused on the pain assessment method and did not involve sensors integration. In this section, we review how sensors are used to assess pain, which helps doctors and patients to get connected in real time. Using connected sensors and devices in health industries, it can reduce challenges faced by doctors. It allows the patients' health and wellness to be evaluated in real-time by sending their health-related information to doctors, family members, and other caretakers as well as alerting the family upon emergency issues. This solves the problem for those elderly who demand home nursing service that can be rather costly.

In clinician-based studies, diagnosis and classification of diseases are based on information collected from physiological reading. Biomedical signal is the potential that facilitates advance monitoring, diagnosis, and treatment planning [34]. The study used a sensor fusion method to classify mental state in terms of relaxed or stressed via case-based reasoning. Minimum Mean Square Error (MMSE) algorithm was applied to differentiate healthy subjects from those stressed subjects. Sensors integration gave more reliable empirical data [34].

Study from [35] analyzed the physiological profile of drivers with the aid of sensors. Four components were delineated in the paper: sensors, local data storage, centralized repository, and application software. A wearable physiological monitoring system was applied to gather physiological data that consists of blood pressure, pulse, and glucometer. The application remotely helped in controlling crash rate and crime events. The research adopted an android-based application installed on the driver's smartphone. The application and the sensors detected the behavior of drivers and data were demanded for physiological monitoring. The experiment applied Hadoop for cloud storage to gather the required data for analysis. Social media accounts of drivers were retrieved to create physiological profile. All medical hardware devices used for the experimental work were linked to the cloud. The connection was made only with the presence of application programming interface libraries that integrated multiple hardware and software platforms.

Some wearable devices with physiological sensors have commonly used a protocol called Bluetooth Smart [36]. The classic Bluetooth differs from Bluetooth Smart. Classic Bluetooth is designed to link two separate worlds of communication, such as linking cellular phones to laptops, downloading data from cellular phone to car or printing wirelessly at home or office. Meanwhile, the Bluetooth Smart is the best choice for wireless innovation technology for any wearable sensor-based products. Bluetooth Smart is a pioneer for the lowest-power within short range.

The Carrier-Sense Multiple Access with Collision Avoidance (CSMA/CA) is a communication protocol that sends physiological signals [11]. Data from sensors can be sent wirelessly or remotely via local area network or internet for analysis. With the technology to monitor multi-patients, health professionals no longer need to perform routines to retrieve the latest health information of patients at medical centers. The advantage of this system is that patients need not get up early for periodic checks in hospital that may cause discomfort amongst the patients. Galvanic Skin Response (GSR) employed ZigBee as its communication protocol to send data to computer [37]. The GSR detected the variance in skin conductance when one felt stressful or vice versa. ZigBee was selected as the communication protocol in the study due to its low-power consumption and its connection to as many as 255 nodes. Besides, the author noted that a previous paper also used ZigBee in a medical healthcare application. In this paper [37], two ZigBee Boards were applied; one to acquire data, while the other to send data to computer.

F. Pain Assessment Applications

In this section, we review the application of pain assessment that is using modern technologies such as mobile apps, a camera with facial expression recognition and etc. A prior study integrated camera to detect the facial expression of the patients in assessing pain [26]. The paper discusses Active Appearance Model (AAM), which is a computer-based behavioral measurement. The implemented system can detect pain based on the changes in facial expressions automatically. A manual observation of facial expression is timely and costly due to the attempts related to posing spontaneous emotions data are subtle and do not occur frequently. Facial Action Unit (AU) detector differentiates fake from genuine pain. The major challenge of detecting facial expression using AAM was the head motion and the facial deformation as it failed to detect similar expressions with varied head motions.

Self-report method in the form of paper-based has been the most commonly used method in pain assessment [12]. There is an iPhone-based application called Pain Squad. This electronic application serves as a pain diary by collecting data on pain intensity, duration, location, and impact on an adolescent's life. Users are prompted 20 questions to answer the level of pain. The data inserted by the users will be sent and stored at the database. This electronic pain diary was implemented for cancer patients, wherein each diary represented the pain felt by the patients. Paper diaries or daily phone calls are a data collection method, whereby both methods have been widely used with each having significant disadvantages [24]. The advantage of this application is that the method can collect pain reports in natural settings (pocket size phones, large memory capacity, user-friendly interface). The application can create time- and date-stamped pain reports, apart from uploading the data to secure databases for review by scientists and clinicians.

A self-report system was developed [13] using mobile phones. The application captured the patient's self-management of hypertension information efficiently. This application had a routine to capture the relevant pain scale of the patients as this system was made available on the patients' mobile phone. It was used to record blood pressure reading, not in real-time using sensors, but separately using other devices, and entered the values manually into the application. Although blood pressure values were recorded in the report, this application was mainly for interactive self-report system to be used by hypertension patients and not for physiological measurement.

The three most common methods (behavioral and physiological methods, and self-report) found in the literature review pertaining to pain assessment have advantages and limitations. Younger J., (2009) asserted that no valid and reliable method that can objectively quantify one's experience of pain. Pain assessment mainly relies on self-report measures to determine the impact of one's pain, which proves that self-report is a method that is reliable and valid, when compared to the other two methods. Cowen [7] supported the benefit of developing and using physiological markers in pain diagnosis by observing derived cardiovascular and respiratory parameters (heart rate variability, patterns of blood pressure, heart rate responses, pulse wave amplitude, and pulse beat interval), skin sweating, and pupillary changes. Implementation of the system in the study had proven the validity of the correlation between the two methods. The next section describes the methodology adopted in this work.

A hybrid technology between physiological measurement and self-report for pain scoring has yet to be implemented. As such, this study presents a hybrid of physiological measurement and self-report techniques as pain assessment method. This hybrid method was applied for data collection. From the literature review, several pain assessment applications have been implemented, whereby most studies focused on the self-report method to assess pain [13]. Some applications offer vast features, apart from assessing pain via self-reporting. For instance, Pain Assessment and Documentation Tool (PADT) is an open source application.

The platform that supports this application consists of iOS, Android, and Windows. PADT contains features of pain relief methods that serve as guide to users for good pain management. PADT embeds a numeric rating scale for pain severity and patient reports. PADT is basically a simple self-report mobile application that offers a simple way to manage patient pain management. Besides self-reporting, a face detection camera for pain assessment was also developed [26]. Among the three methods of assessment, only behavioral method observes the changes in facial expression of patients. The AAM refers to a computer-based behavioral method software program. Camera also had been used to detect patients' facial expression [26]. The limitation of the system is that it identifies precise and accurate pain, thus the suggestion to integrate pain scoring via physiological measurement. However, no study has proposed a pain assessment system that incorporates the hybrid technology of physiological markers and self-report methods.

G. *Proposed Methodology*

The proposed methodology starts with the development of Physiological measurement system followed by mobile system development and finally, system testing. The architecture is shown in Figure 5.

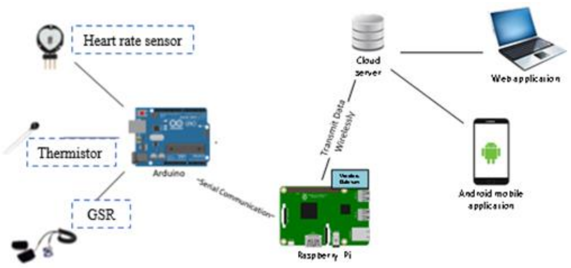

Figure 5: System architecture

In this study, we propose a system hybridizing the physiological measurement and self-report to measure the level of pain. In order to achieve this, we have three phases as shown in Figure 5. For the first phase, the physiological measurement system is implemented by using three different Arduino sensors and a Raspberry Pi. This system will be used to read and store the physiological readings of the authors. The next phase, the mobile application development which will be the platform for the authors to scale their level of pain. The Android mobile application was implemented using JAVA language and can be run at a minimum version of Android 7.0.

System testing is the last phase of this study. It aims to see the functionalities are working correctly and this includes a pilot test to us (on ourselves) just to see if the idea works. The pilot testing phase was voluntarily participated by all the authors involved. The pilot test was done by using the controlled temperature water bath. The procedure of the assessment requires the authors to immerse their hands into a pot filled with a water bath, in which the temperature of the water bath was monitored and controlled. The initial temperature of the water bath for the assessment was set at 5°C, therefore a small pot filled with ice was placed on the hotplate for the first assessment during system testing.

The ice was then increased to another 5°C by using a hot plate or by adding warm water. This step was repeated until the temperature of the water bath reached 5°C, which is the final temperature for the assessment. A thermometer was used to measure the temperature of the ice and water bath in the pot. During the increase of the water bath temperature, the reading of the thermometer was monitored for 10 seconds, after the targeted temperature for the assessment has been reached. During system testing, authors were free to remove their hand from the pot if they cannot stand with the temperature of the assessment. These steps were purposely included in the assessment procedure to avoid any injury during the assessment. The physiological readings were taken continuously, and the authors were asked to score their pain level when they start to immerse their hand into the water bath. The score and the physiological readings were stored in the database with a time stamp. The readings of physiological and the self-report data were observed together with the inclusion of the timestamp. The timestamp of the self-report scale input in the database was compared with the timestamp of the physiological readings taken. An observation was made during the last 10 seconds before the exact timestamp of scale was stored as input in the database. The purpose was to observe the changes in physiological readings when the author is induced to pain. The data of physiological readings were taken from the database by choosing the highest heart rate reading in the range of 10 seconds. The value of GSR and body temperature was taken along with the highest reading of heart rate and recorded into the IBM SPSS Statistic software.

1) Physiological Measurement Development

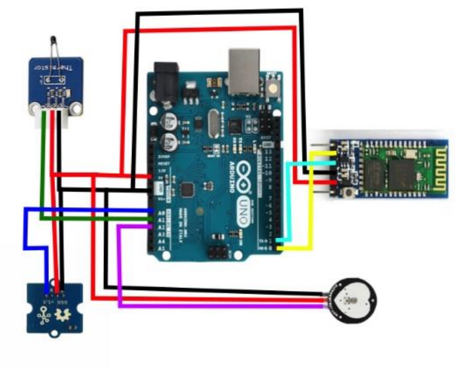

Figure 6: Sensors circuit diagram

This study selected the author to perform system testing. Three sensors were applied for physiological measurement, whereby each sensor took different reading from the patients. The device was attached to the wrist and fingers of the authors to obtain real-time physiological reading. The implementation integrated a Bluetooth component that was connected to Raspberry Pi wirelessly. The data taken from the sensors were sent to Raspberry Pi directly using the Bluetooth connection. The Raspberry Pi was embedded in this system for connection to MySQL server. Raspberry Pi comes with built-in Bluetooth that stored data directly to its localhost server through Python program. All the physiological data of the authors taken using the sensors were stored in database server, as they would be useful for clinicians and nurses to observe and to obtain data regarding patients' health. The sensors, namely the GSR, thermistor, and pulse sensors, enabled the physiological reading on the authors. Thermistor was used to sense body temperature of the authors, while pulse sensor read their heart rate. GSR sensor measured the continuous variations in the electrical characteristics of the skin, which also refers to changes in sweat gland activity that are reflective of user emotional state. All readings and data from the mobile application were stored in the database server. The platforms integrated in this study were web-based and Android mobile applications. The web-based application was for the admin to register or update data from authors on the server. Meanwhile, the Android mobile application was developed to take readings of pain scale scored by authors, which were later stored into the database server. The level of pain and the physiological reading scores were stored in the database and used for analyses to determine the correlation between the reading of pain score and the physiological reading. Correlation validation was conducted to determine the correlation between self-report method and physiological measurement.

2) Self-Report Application Development

Figure 7: Android mobile application interface

The software functioned as the platform for the self-report method since this study mainly focused on the hybrid of physiological measurement and self-reporting method for pain assessment. The actors involved in this system were the admin and the patients. The admin used the web-server to register data related to the authors into the database server. In this system, two platforms were incorporated, the web-based and mobile Android application programming. The web application of the system could only be accessed by admin. The mobile application was used by the authors to score the pain scale prompted in the application.

Recently, mobile phones have been successfully used in the healthcare arena [13]. The program was implemented using Android Java language, whereby the minimum SDK/ API level of the program was 15. The minimum version of Android compatible to run this application program was 4.0 (Ice Cream Sandwich). The application mainly focused on viewing the physiological reading in real-time. The readings were retrieved from the database server. The period of pain assessment was 30 minutes. A question ("What is your current level of pain?") and numeric pain scale were used after every 3 minutes of the pain assessment period for the authors to scale their level of pain intensity. The level of pain scored by the authors was stored into the database server to be used for solution validation. A simple web-based program was developed for the admin to register authors' data. The language of the program was implemented using PHP, CSS, and HTML. This work has been copyrighted under the title of Integrated Bio-Health Sensor and Application for Pain Detection with application number LY2019000354 via Intelectual Property Corporation of Malaysia (MyIPO).

3) System Testing

System testing is taken by taking pain measurement of five authors of this paper. The system testing need to undergo this assessment thrice during system testing, in which the purpose is to compute the mean for each variable. This is because the Pearson correlation formula needs to use continuous data as their variable to find the correlation. There were 30 data per reading (in each system testing,) as there were 10 different temperature per assessment and each authors need to undergo the assessment three times. Pearson correlation formula has been used to find the strength and direction of the correlation between the two methods and it is included in the IBM SPSS Statistics 23 software.

III. RESULT AND DISCUSSION

All scores were stored in the database, along with the latest physiological readings (skin conductance, body temperature, and heart rate) of the authors. From the data, changes in physiological reading and pain score level of the patients were noted for the pain they felt.

This study used Pearson's correlation as it has been commonly used by researchers to determine linear relationship between two variables. For example, Pearson's correlation used in [15] determined the relationship between heart rate and pain, wherein variances were discovered in the gender-based relationship.

Pearson's correlation can produce either positive or negative relationship between two variables - physiological readings and self-report pain score in this study. If there is no linear relationship between the variables, null hypothesis is produced. In this study, one combination result that consisted of three different readings was produced in this study to view the overall hypothesis of this study. The three hypothesis are: (i) H1: If the level of pain increase, then the heart rate will be increase, (ii) H2: If the level of pain increase, then the body temperature will increase and (iii) H3: If the level of pain increase, then the value of GSR should be increase. Overall, the hypothesis reflected the main outcome that determined the relationship between the variables of this study.

Table 1
Correlations Result Between Self-Report Scale (Pain Score) and Physiological Readings

		Pain Score	Heart Rate	Body Temp	GSR Value
Pain-Score	Pearson Correlation	1	0.734**	0.009	0.259*
	Sig.(1-tailed)		0.000	0.0476	0.035
	N	50	50	50	50
Heart rate	Pearson Correlation	0.734**	1	0.120	0.170
	Sig.(1-tailed)	0.000		0.203	0.119
	N	50	50	50	50
Body Temp	Pearson Correlation	0.009	0.120	1	0.090
	Sig.(1-tailed)	0.476	0.203		0.267
	N	50	50	50	50
GSR Value	Pearson Correlation	0.259*	0.170	0.90	1
	Sig.(1-tailed)	0.035	0.119	0.267	
	N	50	50	50	50

**Correlation is significant at the 0.01 level (1-tailed).
*Correlation is significant at the 0.05 level (1-tailed).

Table 1 is based on the system testing, in which all the data were taken from the five authors. Correlations were computed among self-report scale and three physiological readings. The number of data (N) is 50 as all the five authors underwent ten different temperature of assessment. As shown in Table 1, the result of the correlation between the self-report scale value and the physiological readings located at the first column and first row. The correlation between heart rate and self-report is r=+734, P<0.05, one-tailed. The correlation between body temperature and self-report is r=+0.09, P> 0.05, while Pearson correlation for GSR value and self-report is r=+259, P<0.05. The P value shows the significance between two variables, the result suggests that only body temperature variables are not significant with P value = 0.476, which means that this is the only variable that gives a null hypothesis result. Pearson coefficient r value will show that there is a weak relationship between variables when the coefficient value of r is near to 0, and a strong relationship is when r > 0.7. From Table 1, Pearson Correlation (r) of the heart rate shows the highest among the other two variables with self-reports, which shows that heart rate has the strongest correlation with self-report, GSR value shows a moderate relationship and body temperature shows a weak relationship with self-report. Note that self-report refers to self-report scale, which is the pain score.

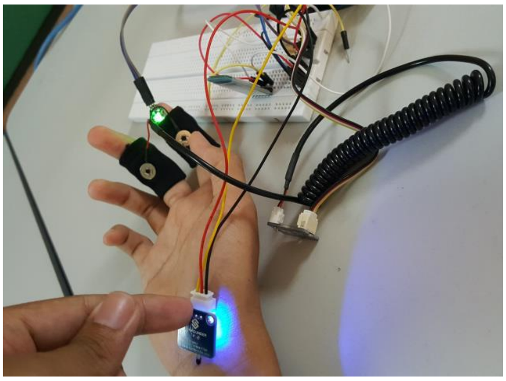

Figure 8: Assessment activity using implemented system

Since this study sought to determine the relationship between physiological readings and pain self-report, the proposed methodology was integrated with pain assessment activity using the implemented device. The device was attached to the wrist of the authors during the assessment, and they had to scale their level of pain on the pain score prompted on the mobile application. Our system testing has shown that there are correlations between readings, which indicates the potential of using physiological marker as predictor for pain. However, this will require an extensive study on the medical sciences. Hence, for future work, this study will need to be done by medical sciences people with clearance from human ethics. A proper assessment needs to devise an experiment that involves human, for example the public or patients, as this study only tested as a usual system development scope. Moreover, this study only tested the functionality and accuracy of the correlation analysis component.

IV. CONCLUSIONS

Many studies have been conducted to find the relationship between behavioral and self-report method; however, only a few of them addresses the connection between physiological measurement and self-report method. This work proposed a scale based on the correlation between self-report method and physiological measurement system using IoT technology and mobile computing. An android app was developed and integrated with sensors for this purpose. From system testing, we were able to observe the relationship of each physiological variable taken with the scale, whether it shows a positive or negative relationship. Insights from the correlation between the physiological readings and authors' pain score level had been made from the scale. The expected pain scale produced consisted of a range of physiological readings on each level. This proposed scale, however, needs further examination and experiment to determine the pain level prediction pattern with hybrid method for future assessment.

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