Design of an Adaptive State Anesthesia Feedback Controller

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Abstract—Anesthesia is critical in medical procedures to ensure the patient's body remains stable and unresponsive during surgery. However, administering the correct dose can be challenging, particularly in prolonged surgeries. An auto-controlled system that incorporates vital sensors and a microprocessor controller has been pro-posed to address this issue. This system uses an infusion pump to provide the correct amount of anesthetic based on the patient's vital signs. The microprocessor takes control of the system once initiated and signals the motor driver to start injecting the required amount of anesthesia while monitoring vital signs such as temperature, heartbeat, and Spo2. The system alerts the doctor if any abnormality is detected, and the supply of anesthetic is stopped until everything returns to normal. This system ensures accurate anesthetic dosage, minimizing the risk of complications and ensuring a safe surgical procedure.

Keywords—automatic adaptive state, embedded system, arduino, vital parameters, infusion

1 Introduction

The patient must be under anesthesia to undergo any procedure. By administering anesthetics, doctors can temporarily make a patient unconscious so they won't feel any pain throughout an operation [1]. The effects of the anesthetic should be seen regardless of how long the procedure lasts; thus, they are given at predetermined intervals. Long procedures lasting up to four hours or longer shouldn't receive the whole dosage of anesthetic all at once. since a high dose could result in the patient developing serious complications [2].

It encompasses muscle loosening, insensibility, and pain-relieving [3]. Anesthesia is classified into three types: regional, general and local. General-anesthesia is primarily utilized to unconscious the patient during big surgeries [4][5], Local can be utilized to numb the specific regions of the patient's body [6], on the other hand, can be utilized to relieve pain in a certain area of the body, such as a leg or arm [7]. There are two types of methods by which anesthesia can be delivered to the patient intravascular injection and inhalation [8][9]. Patients respond quickly when given intravenous anesthesia [10][11].

In current clinical practice, an anesthesia specialist administers anesthesia to the patient using a manual system. an anesthesia specialist must monitor the patient's physiological signals and trends to determine the appropriate anesthetic doses. De-pending on the variability of the patient's characteristics, this process may overload anesthesiologists. As a result, the anesthesiologist might not provide the patient with the prescribed dosages of anesthesia. Inadequate dose administration, including high or low doses, can lead to complicated situations for the patient, such as coma in the situation of excessive doses and awakening through surgery in the situation of low doses [12]. In this context, there is a need to automate the anesthesia processes to reduce human error and anesthesiologists' repetitive tasks which provide more time for them to take direct care of patients [13]. In recent days embedded systems are used in many medical applications to control different vital parameters [14][15].

2 Related works

Numerous research projects relating to the automatic anesthesia controller have been conducted and are constantly being worked on. A. Lowe 1998 designed A fuzzy PID controller using 25 principles to control the drug delivery unit. The work used mathematical models that respond to specific drugs that mimic the human cardio-vascular system [16]. Rohan K. 2008 designed an automatic operation for the anesthesia machine based on electroencephalogram (EEG) features to estimate the depth of anesthesia. They conclude Although EEG provide sufficient input of depth of anesthesia but it can't monitor the whole complexity of the anesthesia. So, combining EEG features with other bio parameters is significant to result in more confident indices of the depth of anesthesia [17]. Dipti S. 2012 introduce an automatic fuzzy controller system that uses linguistic fuzzy rules for controlling the anesthesia dose with respect to input parameters. The anesthesia dose was calculated based on the analysis age, weight, and height parameters of a patient [18]. Jagannath W. 2016 designed a fuzzy logic-based support system that mimics the doctor's decision due to the inputs. They used heart rate, Spo2, and blood pressure parameters as continuous input parameters of the fuzzy decision support system and Lab-view Graphical user interface (GUI) [19]. Rishabh G. 2019 designed an automatic anesthesia injector system that manages the amount of anesthesia of a specific surgery based on different types of feedback vital parameters with the patient's EEC signal. They observed that the anesthesia dose needed for the specific surgery is calculated accurately [20]. Claudia P. 2020 utilized the SEDLine monitor to explain the technical and clinical performance of a closed loop system for complete intravenous anesthesia with propofol and remifentanil. Three healthcare facilities and 93 patients provided the data. Their result obtained showed that a closed-loop complete intravenous anesthetic system with SEDLine was utilized without any significant complications and ap-pears to be practical for use in clinical practice [21]. R. Kumar 2021 designed an actual control and monitoring of anesthesia dose provided to the patient during the surgery. They utilized heart rate and blood pressure parameters with a switching relay controller to manage the provided anesthesia dose [22].

This paper's main objective is to combine physiological parameter monitoring with the anesthetic system in order to give a correct dose of anesthesia and simultaneously monitor vital signs [23]. The stepper motor rotates at the desired speed thanks to the microprocessor controller, which receives programmed input. The infusion pump rotates forward and backward when the stepper motor starts in order to administer anesthetic to the patient. Vital parameters and vital sensors are measured side by side to prevent issues in vital parameters when administering anesthetic. The American Society of Anesthesiologists states that following anesthetic administration, physio-logical variables including temperature, SpO2, heart rate, blood pressure, and ensuring appropriate breathing must be monitored [24]. These metrics have an electric buzzer attached to warn the anesthesiologist if anything changes.

3 Materials and methods

The system proposed monitoring vital parameters with the anesthesia system to administer physiological parameters and anesthetic at a precise dose. The microprocessor controller receives programmed vital input from the biosensors, which causes the stepper motor to rotate at the proper speed and move the infusion pump to transfer the anesthetic into the patient's body. Figure 1 shows the microcontroller board used (Arduino Mega 2560 Pinout) which is based on the ATmega328 and equipped with 54 digital input-output pins, 16 analog inputs, a 16 MHz ceramic resonator, a Universal Serial Bus (USB) connection, a power jack, an ICSP header, transmit (TX) and receive (RX) LEDs, and a reset button. It can operate on an external supply of 6 to 20 volts.

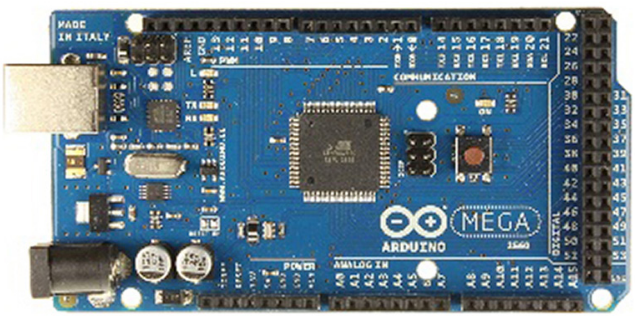

Fig. 1. Arduino mega

Figure 2 shows The MAX30100 is a sensor that measures HR/min as well as the percentage of oxygen in the blood. Two LEDs are employed in the sensor: one emits infrared light to detect HR, and the other emits red light to measure with the infrared one the blood concentration of oxygen.

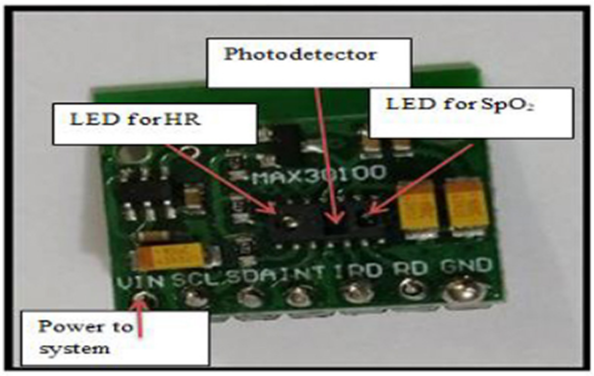

Fig. 2. MAX30100 sensor

This sensor is programmed to automatically compute the Spo2 according to eq.1

$$Spo2 = 110 - 25\left(\frac{RED\ LED\ Level}{IR\ LED\ Level}\right) \tag{1}$$

Figure 3 shows the MLX90614 is an infrared radiation-based temperature measurement system. Due to the fact that it offers a non-contact temperature measurement, it is the optimum alternative for these applications. It is made up of an effective digital signal processor (DSP), a 17-bit analog-to-digital converter, and a squat nasal amplifier. These elements offer the sensor a high degree of precision. This sensor processes the output using an infrared light detector and Advanced Solid-State Photonics (ASSP) signal conditioner [25].

Fig. 3. MLX90614 sensor

In Figure 4, a 28BYJ-48 stepper motor is shown. divides a full rotation into several stages, allowing the infusion syringe to move smoothly while still delivering the appropriate dose. It operates on the electromagnetism theory and includes a 5-wire unipolar stepper motor that generally draws 240 mA at 5 volts. The 28BYJ-48 motor's data sheet states that when it is run in full step mode, each step translates to a rotation of 11.25°. As a result, each revolution consists of 32 steps (360°/11.25° = 32). A ULN2003-based driver board is utilized to manage the 28BYJ-48 stepper motor because it uses a lot of current [26].

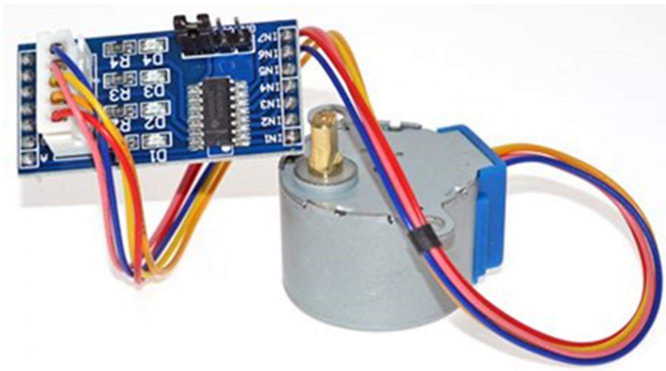

Fig. 4. 28BYJ-48 Stepper motor

Infusion syringe are used as precise dosing systems or to accurately deliver small quantities of doses throughout the experiment.

Figure 5 shows the specific block design of the suggested automatic anesthetic control system. A Stepper motor integrated with a mechanical design is used as infusion pump system to control the amount of anesthesia dose injected into the patient via infusion syringe. While administering the anesthetic dose, vital sensors are utilized to monitor the patient's vital signs and inform the anesthesiologist through a buzzer if any abnormalities arise.

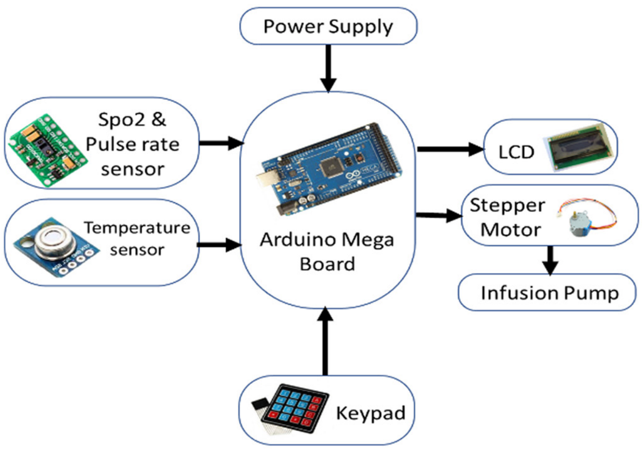

Fig. 5. Block schematic of the automatic anesthesia control system in general

The mechanical design consists of shift and wheels serrated that are designed and printed using a 3D printer. The serrated wheel was placed above the stepper motor and the serrated shift was fixed on the base of a plastic car possessing wheels as shown in Figure 6.

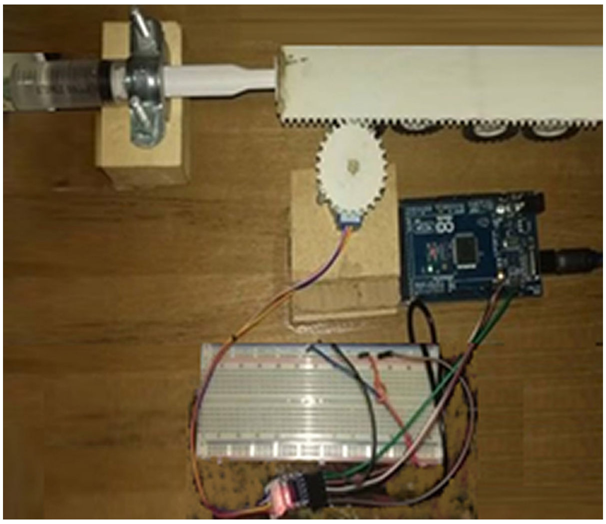

Fig. 6. The mechanical design integrated with Stepper motor and infusion syringe

The Infusion system was nourished with a light emitting diode on one side and a photocell on the other side which connected to a voltage divider circuit to calculate the amount of anesthesia in the pump as illustrated in the Figure 7.

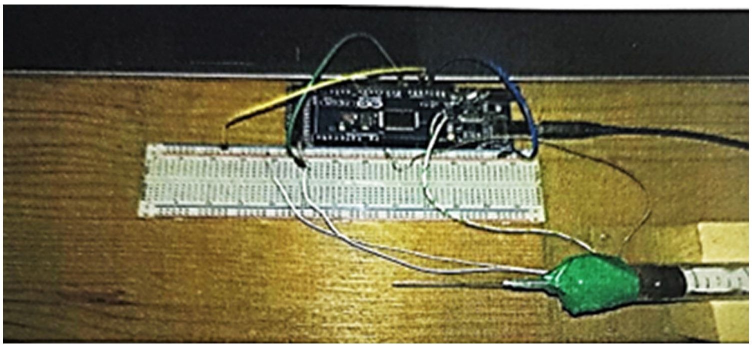

Fig. 7. Dose controlling system

When the anesthesia has drained the plunger of the syringe is totally cut the light which decreases the photocell resistance that changes the voltage. Using an Arduino, the stepper motor was programmed to step 420 steps to make the infusion pump deliver 1 ml.

Keypad was connected to the Arduino to enter the data as patient weight, amount of drug in terms of micro mg/kg/min, maximum and minimum vital signs (HR, Spo2, and Temp.), and syringe concentration. As illustrated in the schematic diagram in Figure 8.

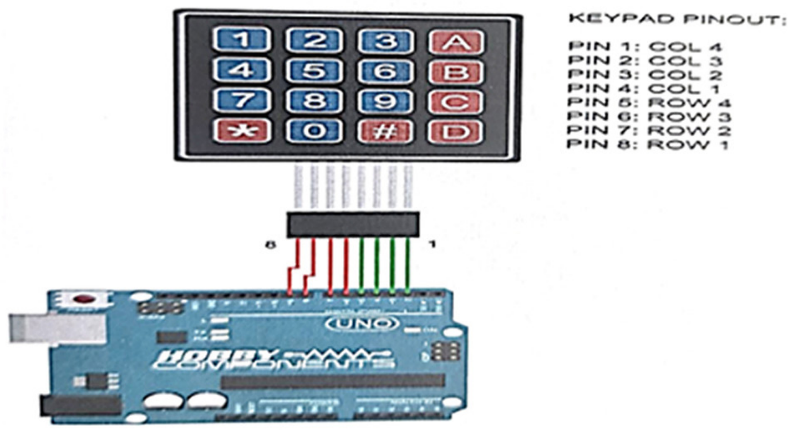

Fig. 8. The schematic diagram Keypad system

The mechanism started by running the automatic anesthesia control system and inputting the number of doses to be administered. the operation of calculating the number of doses represents the number of motor steps required to pump the specified amount which calculated as

$$A_2 = A_1 \times W \times 60$$

$$A_3 = A_2 / 1000$$

$$A_4 = A_3 / \text{syringe concentration}$$

$$\text{Motor Steps} = A_4 \times 420$$

Where A_1 represented the amount of first drug entered in terms of micro mg/kg/min, A_2 represented the amount of drug in terms of mg/hr, A_3 represented the amount of drug in terms of ml/hr, and 420 represent the number of steps that required to pumping 1 ml of syringe.

After the first dose pumped the system checks for the inputs from the sensors and varies if the vital signs are normal. If they are normal, the next dose is injected by the stepper motor, if it is abnormal, then it alerts the doctor by an electric buzzer as well as displaying on the LCD. This process will be repeated for the specified number of doses as illustrated in Figure 9.

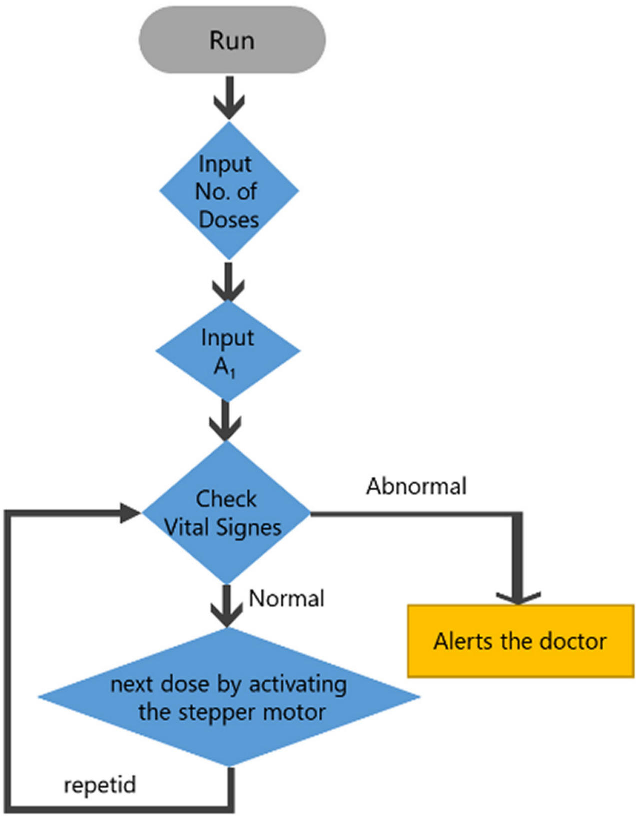

Fig. 9. Flowchart of the system mechanism

4 Results and discussion

The number of doses required represents the input for the proposed system, and measurements are made of parameters including temperature, heart rate, and Spo2.

The value of the measured vital signs affects the stepper motor's movements. If the vital signs are normal, the stepper motor moves and it is displayed so on the LCD screen. If there is any abnormality, the stepper motor stop and the doctor is alerted by an electric buzzer as well as the values displayed in the LCD panel.

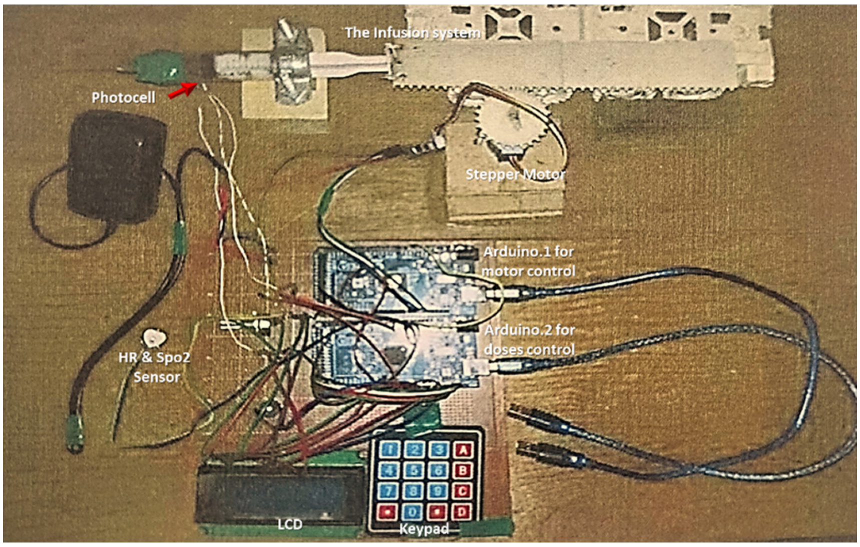

Fig. 10. Final implementation of the system

In the final implementation of the system, shown in Figure 10, performance evaluation was given in two phases. First, the vital sign sensors were evaluated by comparing the results with Byoned digital pulse oximetry and the XD-58C temperature sensor which are used in the hospital (CE approval). The results were obtained from ten people from various age groups to compare the variance of the measurement between the two systems as illustrated in Table 1. Comparing CE approval values to the proposed system values, the results differ by about ±2 degrees. Therefore, the suggested method is capable of identifying any changes that have directly affected the patient. Secondly, the accuracy of the pumped drug amount was tested in response to the microcontrollers used and the stepper motor.

Table 1. Analysis of patients' real-time vital signs measurements

Pt.	Age	Proposed System			Approval Byoned Digital Pulse Oximetry and XD-58C System		
		SPO2	Temp. (°C)	HR	SPO2	Temp. (°C)	HR
1	28	96	36.8	81	97	36.7	82
2	26	98	37.1	83	99	37	84
3	58	97	36.5	63	96	36.8	62
4	30	96	36.7	80	97	36.9	81
5	15	98	36.3	89	99	36.7	88
6	56	96	36.7	62	97	37	61
7	19	99	36.8	85	98	37	86
8	35	98	36.6	78	99	36.8	79
9	42	97	37	64	96	36.9	63
10	24	98	36.8	87	97	37	88

5 Conclusion

Monitoring patient parameters is highly important when the patient is under anesthesia, according to the project's overall methodology. Anesthesiologists have difficulty keeping concentration while performing multiple tasks. To alert the anesthesiologist if anything unusual happens while administering an anesthetic to the patient through a syringe-pump, which is in turn controlled by a stepper-motor, an embedded patient monitoring system has been built with various sensors. Integrating monitoring parameters into an automatic anesthetic control system improves patient safety. An anesthesia doctor is alerted by an electric buzzer if any abnormalities in vital parameters occur. The proposed system enables the anesthesiologists to combine physiological parameter monitoring with the anesthetic system in order to give a correct dose of anesthesia and simultaneously monitor vital signs. An anesthesiologist is alerted by an electric buzzer if any abnormalities in vital parameters occur. The system presented a satisfactory performance with an average disparity of less than 2% in vital signs readings and dose amount accuracy.

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