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Simulated Blood Glucose Meter Design for Educational Simulation in Healthcare

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SIMULATED BLOOD GLUCOSE METER DESIGN

FOR EDUCATIONAL SIMULATION

IN HEALTHCARE

by

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ABSTRACT

SIMULATED BLOOD GLUCOSE METER DESIGN

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The University of Texas at Arlington, 2022

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A commonly performed point-of-care test is the measurement of a patient's blood glucose, a process currently practiced in healthcare simulation with minimal realism at UTA's Smart Hospital. Training of healthcare professionals involves essential skill development and proficiency, which cannot be done effectively with low-fidelity props. A device was developed with consideration of the types of scenarios run at the facility and coded to be prototyped with Arduino. The device's circuit setup and function were simulated using Tinkercad to assess the desired output values in the three glucose ranges: hypoglycemic, normal, and hyperglycemic. Successful generation of random glucose readings in these ranges was achieved. The SolidWorks model of its external housing resembles glucose meters on the market with the ability to insert and remove test strips.

The blueprint design is open for further modification and optimization to improve functionality and eventual production of a physical prototype.

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CHAPTER 1

INTRODUCTION

During my Bioengineering Internship at the Smart Hospital under the UTA College of Nursing and Health Innovation (CONHI), I was exposed to several needs in the simulation facility for cost-effective equipment that would contribute to the realism of the teaching scenarios. Our internship group developed a simulated thermometer that resembles a clinical thermometer and displays randomly generated temperature readings in different.

Similarly, there is need for a simulated blood glucose meter to provide glucose readings when running simulations with manikins or standardized patients. Currently, during scenarios, when glucose is being measured, a blood glucometer with a reading taped over the display screen is used. This value can be changed depending on the situation being simulated. Unfortunately, this does not contribute to the realism of the practice, especially when a scenario involves multiple measurements of glucose levels or changes in the glucose levels within a single scenario.

Furthermore, while the readings can be switched out and students briefed on the unrealistic aspects of the scenario to overlook, it adds to the preparation efforts for each simulation. Multiple pieces of equipment being simulated in the same manner result in more devices needing this kind of attention. The goal of the project is to design a device that will produce blood glucose readings that will not be the same each time and do not require manual replacement or added intervention by the educators. Ideally, it will function like an actual glucometer in terms of producing a reading when used with a test strip.

CHAPTER 2

LITERATURE REVIEW

2.1 Summary of Peer-Reviewed Literature

According to the National Diabetes Statistics Report published by the CDC, 10.5%
of the US population are living with diabetes, which amounts to 34.2 million individuals.
Taking into consideration the 88 million who are classified as prediabetic, that is an even
greater percentage of the population who would require regular blood glucose monitoring
especially when visiting a healthcare provider [1]. Point-of-care (POC) tests, like obtaining
a patient's blood glucose supply information that can be used to make decisions at the
bedside rather than sending such tests to the laboratory to be run which can be time
consuming. The POC tests enable rapid decision making and implementation of treatment
to fast changing glucose levels [2].

Fidelity in healthcare simulation refers to an intrinsic property that is crucial to
simulation design and to educational effectiveness and depends on the learners' perceived
realism of the context of the scenario they are playing out. Accurate representation of real-
world cues and stimuli is what contributes to a more realistic experience not necessarily
the complete replication of every aspect or use of the current medical grade equipment [3].
An existing device on the market for nursing simulations is the battery powered and
interactive GlucoSIM (Figure 1.1). It looks and feels like a real glucose meter. Instructors
can program up to two readings using the LED touch screen for the students to react and

respond when they measure blood glucose during a simulation. Currently, this device costs around $460.00 [4].

Figure 2.1: GlucoSIM Device by Pocket Nurse
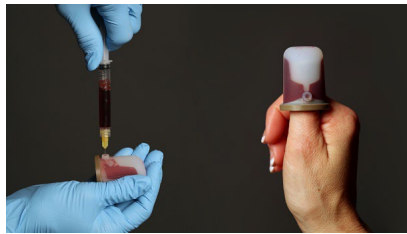
Figure 2.2: SAFingerStick by JC3 Innovations

Healthcare simulations also make use of task trainers for like the Lance or the SAFingerStick (Figure 1.2). These kits range from $90-110 and include a sleeve that goes over the fingertip, a syringe, and simulation blood. The simulation blood can then be assessed using a standard glucose meter. Lance is also available without the blood fill kit [5].

By the same name, an educational software called GLUCOSIM is used to simulate patients who are healthy, diabetic, and undergoing a glucose tolerance test. The software package, originally developed in MATLAB, simulates blood glucose and insulin dynamics in healthy individuals and patients with type 1 diabetes. It allows visualization of the dynamic changes in blood glucose levels in response to food consumption and insulin administration. The nutritional database supplies a sophisticated integration of meal inputs

and selection of insulin doses to the simulation, which then applies various mathematical models to mimic their effects on blood glucose [6].

2.2 Significance

Based on the prevalence of diabetes and the fact that blood glucose testing is part a patients vital signs assessment, nursing students at the CONHI would greatly benefit from the realistic practice of the process of obtaining those readings and be able to make quick judgements in the scenario. Having an instructor cue in the glucose values or devices with a reading taped on reduce the realism of the experience. Since the cues and stimuli offer higher fidelity, using a device the size and shape of a glucose meter like GlucoSIM, accompanied by the needle stick allows them to experience the actual test is performed. The wearable fingertip without the blood can be used as it avoids the mess and allows practice of the needle stick, and the simulated glucose meter can be designed to respond to insertion of a test strip.

The educational GLUCOSIM software provides insight into considerations to be made when designing a device with similar function. With existing products, the costs are a principal factor. The devices are costly and sometimes require extra programming and parts are not always reusable. The device to be designed is intended to curb the purchase of a product like GlucoSIM while still serving the needed purpose and offering realism.

2.3 Design Specifications

Working closely with the Smart Hospital's Simulation Technology Manager, Ms. Erica Hinojosa and faculty mentor Dr. Cheng-Jen Chuong, the specifications and extent of sophistication of function expected was decided. Additionally, having explored the possibilities for simulated glucose meters and taking into consideration the timeframe to produce a substantial design that addresses the needs, the trigger of value outputs by button presses was prioritized over other more complex functions. The initial iteration of the

device does not need to perform the calculations based on administration of medications as per the Smart Hospital needs. The blood glucose meter being designed should not require added intervention by the educators and must solely be operated by the students during the simulation providing them with the needed patient information for that simulation. To allow for different ranges of values to output as scenarios may involve hypoglycemic, healthy, and hyperglycemic encounters, three blood glucose ranges will be incorporated into the device code (Table 1.1).

Table 2.1: Three Blood Glucose Ranges to be Output by the Device [7]

Blood Glucose State	Range of Values (mg/dl)
Low	40-69.9
Normal	70-139.9
High	140-250

The low state represents values in the hypoglycemic range, normal state is the normal and healthy range, and the high state represents those in the hyperglycemic range. These settings will be based on fasting blood glucose values and a normal post prandial reading could simply fall within the high range when scenarios have a patient who has eaten.

CHAPTER 3

METHODOLOGY

3.1 Tinkercad Circuit

For device prototyping, Arduino was selected to make up the electronic components of the device. The code for the simulated glucose meter was developed to be run via Arduino IDE and uploaded to an Arduino Uno board. The needed components for the circuit of the simulated glucose meter are a bread board, an Arduino Uno, an LCD screen, four buttons, five 1kΩ resistors, a potentiometer to control the LCD screen, and connecting wires. Outside of the circuit simulation, a battery connected to a power module is required to power the device. The schematic of the circuit is shown in Figure 3.1.
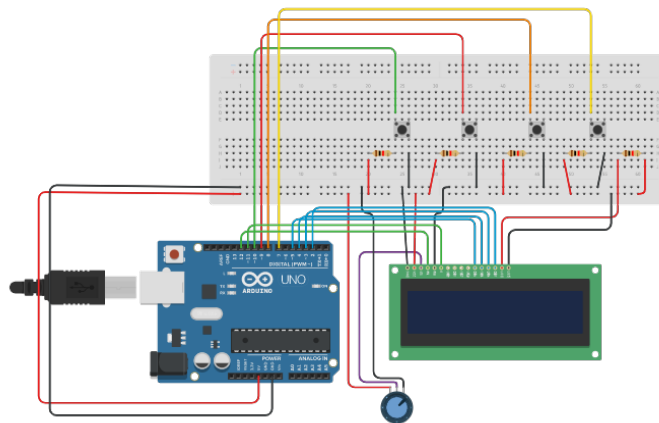

Figure 3.1: Circuit Schematic in Tinkercad

Major connections on the circuit:

- The red lines excluding the one coming off the Button 3, second from the left, represent power while the black wires are ground.

- The four buttons and LCD screen are each connected to a resistor.

- The LCD screen connects at digital ports 3-5, 11, 12, and to the potentiometer.

- Button 1 connects at digital port 7 shown by the yellow wire.

- Button 2 connects at digital port 8 shown by the orange wire.

- Button 3 connects at digital port 9 shown by the red wire.

- Button 4 connects at digital port 10 shown by the green wire.

3.2 Arduino Code

The language used is C++ and the full code with comments describing parts of the code can be found in Appendix A [8]. The first section of the code sets the initial digital read variables and identifies locations of ports on the circuit board from where signals will be sent and received. Variable for holding the random numbers were declared. In the setup section, the button locations are set as input ports. Time delays and wait times are in milliseconds and control the time between measurement and readings and how long the readings stay on the screen. Once the variables were declared, the loop section was coded.

In the loop section, the 'random' function was used to generate the random glucose values in the desired ranges such that they will be output with one decimal place. Then using if statements the mode settings were programmed to based on the button clicked that change the value of the variable 'GlucMode'. The mode selected is then to output on the LCD screen. Based on the previous mode selection, the outputs displayed upon pressing the trigger button are determined by a three case statements. In all cases, the display screen is programmed to read 'measuring…' before outputting the random number from the corresponding range to the case. The device remains in the same previously selected mode

until another mode is selected and the trigger button can be pressed repeatedly to obtain

more readings in the desired range.

CHAPTER 4

RESULTS

To test the programmed code in conjunction with the circuit model, a simulation was run in Tinkercad. The measurements obtained are shown below in Figure 4.1. First a glucose range is selected displaying as the mode and then the button connected to the green wires is pressed to trigger measurement and display of the blood glucose reading.
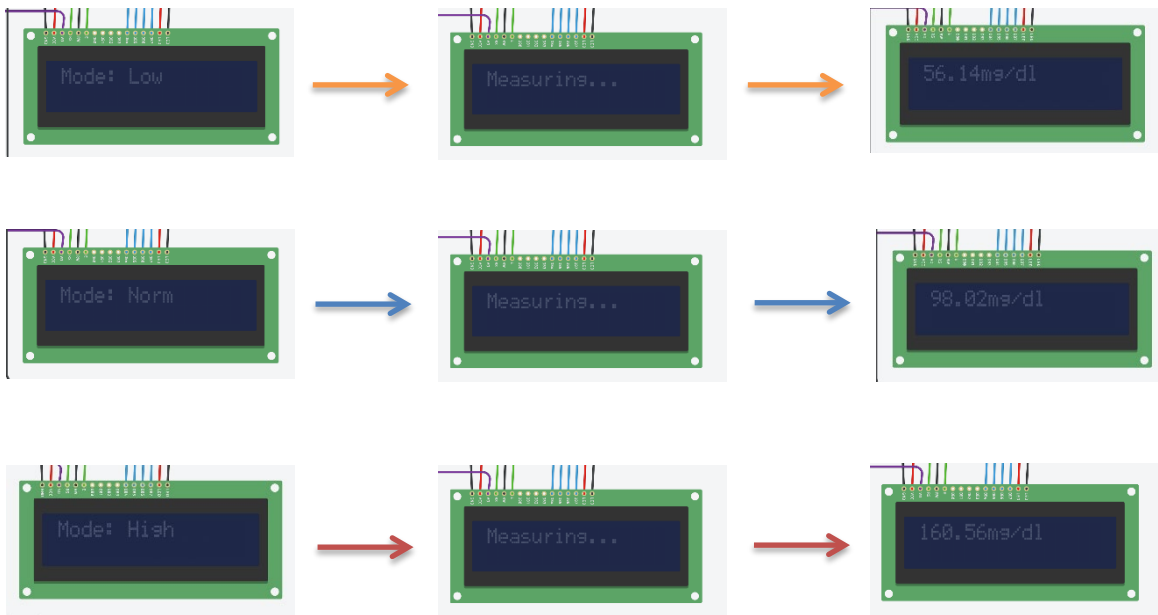

Figure 4.1: Tinkercad Simulation Results: Low Reading (Orange Path), Normal Reading (Blue Path), High Reading (Red Path)

CHAPTER 5

DISCUSSION AND CONCLUSION

The designed code and circuit successfully generate randomized blood glucose readings in the three desired ranges, which can be selected based on the scenario being run. There is room for further development of function. A desired function would be the storage of 3 to 5 of the most recent readings as variables that can be recalled. The size of the circuit components must also be perfected to avoid producing a bulky and less realistic product than the currently implemented props. Arduino Nanos and circuit PCB's will enable down-sizing of the components.

Upon size optimization, a casing to house the parts and fix the display screen can be designed that resembles a common blood glucose meter. Ideally, insertion of a test trip with a delay would function as the trigger and prompt a glucose measurement. Finally, to ensure confirm the improvement and enhancement offered by the simulated blood glucose meter, the device use can be tested among groups of nursing students at the Smart Hospital while a control group goes through simulations using the existing props. An assessment can then be designed to ascertain whether there was a significant improvement in the educational experience or stronger competency.

APPENDIX A

FULL PROGRAMMED CODE

```cpp
// C++ code

// Introducing variables
#include <LiquidCrystal.h>
const int rs = 12, en = 11, d4 = 5, d5 = 4, d6 = 3, d7 = 2;
LiquidCrystal lcd(rs, en, d4, d5, d6, d7);

int GlucMode = 0;

//port numbers
int butt1 = 7;
int butt2 = 8;
int butt3 = 9;
int butt4 = 10;

//digital read variables
int normMode;
int lowMode;
int highMode;
int trigger;
int wt = 1000; //wait time
int dt = 100; //delay time
int swt = 1000; //screen

//variables holding the random number
float randNum1;
float randNum2;
float randNum3;

void setup()
{

  Serial.begin(9600);
  lcd.begin(16,2);
  pinMode(LED_BUILTIN, OUTPUT);


  //sets the button location as input ports
  pinMode(butt1,INPUT);
  pinMode(butt2,INPUT);
  pinMode(butt3,INPUT);
  pinMode(butt4,INPUT);

  randomSeed(A0);
}
```

```
void loop()
{
 //Turn display on
 lcd.display();


 //normal glucose ranges
 randNum1 = random(7000,13990)/100.0;

 //low glucose ranges
 randNum2 = random(4000,6990)/100.0;

 //high glucose ranges
 randNum3 = random(14000,30000)/100.0;

 //Set the variables to the values at the ports
 normMode = digitalRead(butt1);
 lowMode = digitalRead(butt2);
 highMode = digitalRead(butt3);
 trigger = digitalRead(butt4);

 //If the first button pressed
 if(normMode == LOW){
   GlucMode = 1;
   Serial.println("Mode set: Norm");
   //output on Monitor
   lcd.print("Mode: Norm");
   //output on the LCD
   delay(swt);
   lcd.clear();
 }

 //If the second button pressed to set to low mode
 if(lowMode == LOW){
   GlucMode = 2;
   Serial.println("Mode set: Low");
   lcd.print("Mode: Low");
   delay(swt);
   lcd.clear();
 }

 //If the third button pressed set to high mode
 if(highMode == LOW){
   GlucMode = 3;
   Serial.println("Mode set: High");
   lcd.print("Mode: High");
```

```
  delay(swt);
  lcd.clear();
}
else{
}

//Serial.println(GlucMode);

//If trigger is pressed
if(trigger == LOW){

  //switch case instead of if logic
  switch(GlucMode){

    //checks to see which "mode" or case
    //the variable was set on
    case 1:
        Serial.println("Measuring...");
        Serial.println(randNum1);
        lcd.print("Measuring...");
        delay(wt);
        lcd.clear();
        lcd.print(randNum1);
        lcd.print("mg/dl");
      break;
    case 2:
        Serial.println("Measuring...");
        Serial.println(randNum2);
        lcd.print("Measuring...");
        delay(wt);
        lcd.clear();
        lcd.print(randNum2);
        lcd.print("mg/dl");
        break;
    case 3:
        Serial.println("Measuring...");
        Serial.println(randNum3);
        lcd.print("Measuring...");
        delay(wt);
        lcd.clear();
        lcd.print(randNum3);
        lcd.print("mg/dl");
        break;
  }
  //length of time data stays on screen
  delay(3000);
```

```
    lcd.clear();


  }
  delay(dt);
}
```

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BIOGRAPHICAL INFORMATION

Mayur Bhakta transferred to the University of Texas at Arlington (UTA) from Tarrant County College—Southeast where he acquired both an Associate of Science and Associate of Arts in 2019. He declared Biomedical Engineering as his major upon entering UTA and followed the department's tissue track. Being a premedical student, Mayur completed the prerequisite courses for medical school alongside is Biomedical Engineering coursework. His internship at the Smart Hospital which led to his Honors Senior Project merged the bioengineering field with his interests in medical education.

Under the mentorship of Dr. Baohong Yuan and graduate student Yang Liu, Mayur's senior design group had the opportunity to design a fluorescent seed for breast tumor localization via multiple imaging modalities. Their project earned them Honorable Mention at the 2022 UTA Innovation Day.

Mayur intends on continuing to apply this Biomedical Engineering knowledge by pursuing projects that allow him to make a positive impact on healthcare delivery and training. He will proudly draw from these experiences during his medical education, offering a diverse perspective to his medical school cohort and later as a physician.