INDIAN INSTITUTE OF SCIENCE

IISC QUANTUM TECHNOLOGY INITIATIVE

NE223 - ANALOG CIRCUITS AND EMBEDDED SYSTEM FOR SENSORS

Project Report

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Contents

1 Inverted Pendulum

An inverted pendulum is inherently unstable. In this project, a game that can be played by one person, to stabilize an inverted pendulum mounted on a linear motor or a wheeled chassis with a motor drive via a pin joint which allows free rotation of the pendulum, is designed.

1.1 The Manual Mode

1. The game should begin when the pendulum is set upright within +/-5° and this should be indicated to the player with a green LED and a single beep of a buzzer that lasts for 2 seconds.

2. After the pendulum falls beyond +/-85°, the game is over, and the LED should turn off and 3 beeps should sound each lasting 1 second with 1 second interval. Use a LED display to show the time for which the player kept the pendulum upright.

3. Develop a method to detect if the player is cheating by holding the pendulum upright by hand. If they are cheating, display red light and the game is over which is accompanied by the same indicators as stated above.

1.2 The Automated mode

Furthermore, add a functionality of flicking a switch to automated mode where the user input is ignored, and the program automatically controls the motor to maintain the balance of the pendulum without human input. If at any point, the switch is flicked back to manual mode, the game begins (with all the notifications to the user as stated above).

2 Schematic

Based on the rules of the game, various inputs and outputs to the microprocessor are recognised and the schematic of the machine is drawn.
The schematic of the system is shown in Fig. 1.

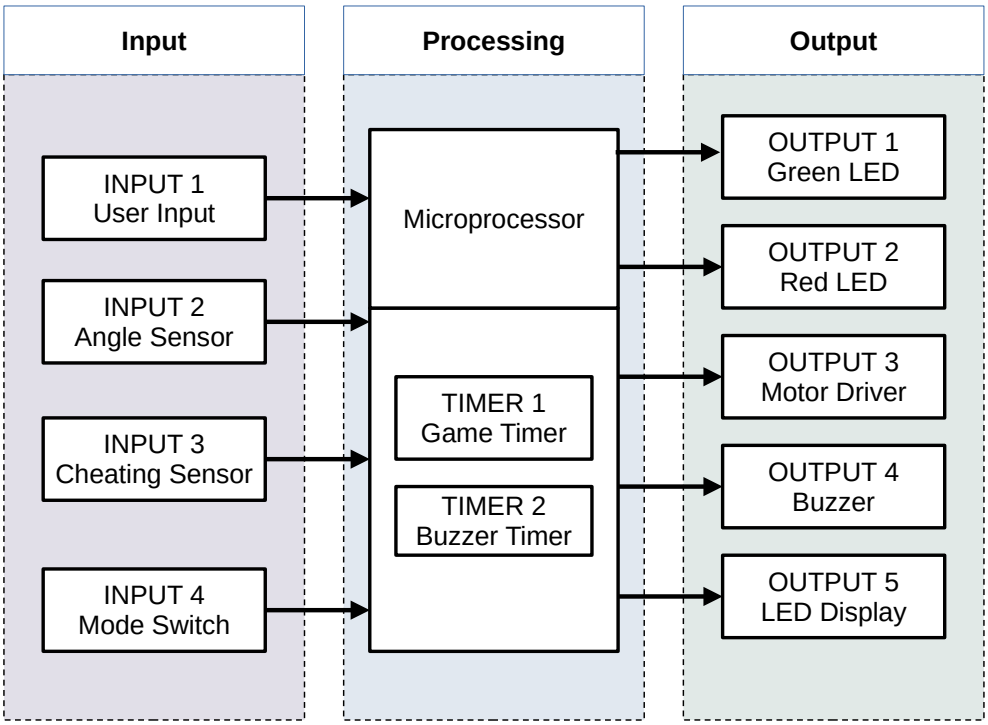

Figure 1: System Schematic of the inverted pendulum game

3 Mechanical parts

3.1 Pendulum

The pendulum is chosen to be of a **cylindrical** shape.
This choice is made to facilitate a uniform and easy attachment of aluminium foil on its surface which is required for the touch sensor to detect cheating.This also means that the pendulum can be chosen to be a section of a pipe or any ordinary cylindrical item and does not need special manufacturing.

Figure 2: Pendulums

3.2 Wheeled Cart

An axle and wheel arrangement can be used. Any wheeled car/-toy can be dismantled and the internal structure can be replaced by the following electronic circuit so that a motor controls the direction and speed of the cart. The cart can hence move only forward or backward (left or right from the side view). The pendulum can be attached to the axle of the wheels.

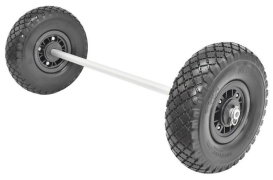

Figure 3: Axle with wheels

4 Inputs

4.1 User Input

This device reads the input fed by the user, that specifies the variables for the desired motion of the motor to balance the inverted pendulum. The input device chosen for this purpose is a **Joystick**.
The Analog Joystick is similar to two potentiometers connected together, one for the vertical movement (Y-axis) and other for the horizontal movement (X-axis). For this project only one direction is required so we will choose the X-axis measurements.

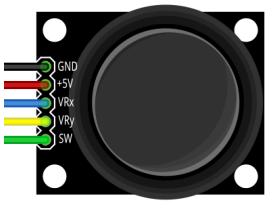

Figure 4: Joystick

4.2 Angle Sensor

This device measures the angle of the inverted pendulum and sends it to the microprocessors. We use the sensors **MPU6050** in the circuit for this function. The MPU6050 consist of 3-axis Gyroscope with Micro Electro Mechanical System(MEMS) technology. It is used to detect rotational velocity along the X, Y, Z axes.

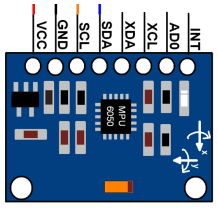

Figure 5: MPU6050

4.3 Cheating Sensor

This sensor detects if the pendulum is being held upright by hand. MPR121 is a capacitive touch sensor controller driven by an I2C interface. The chip can control up to twelve individual electrodes, as well as a simulated thirteenth electrode. The MPR121 also features eight LED driving pins, when these pins are not configured as electrodes, they may be used to drive LEDs. We use the Red LED to indicate cheating The pull-up resistors are also preincluded.
The pendulum is enclosed on an aluminium foil and the foil is connected to the electrodes on the MPR121 touch sensor.

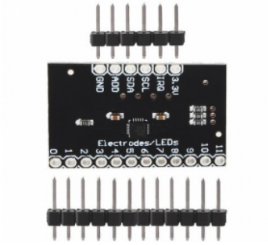

Figure 6: Touch sensor

4.4 Switch to decide Game Mode

This switch decides whether the game in the manual mode or automated mode. A **toggle switch** can be used so that one setting turns the game to manual and the other makes it automatic. In the automated mode, the inputs from the user are ignored.

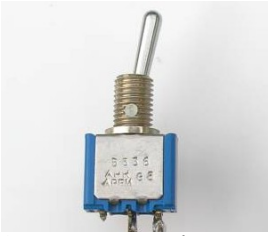

Figure 7: Toggle switch

5 Microprocessor

The microprocessor used is Arduino Uno. Arduino Uno is a microcontroller board based on the ATmega328P. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz quartz crystal, a USB connection, a power jack, an ICSP header and a reset button.

We use two of the timers for various functionalities.

1. Game Timer: This timer starts when the game begins and stops when it ends. The time from this timer is displayed in the LED display.

2. Buzzer Time: This time is used to time the buzzer beeps, when the game begins and ends.

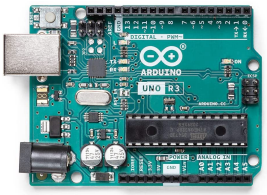

Figure 8: Arduino Uno

6 Outputs

6.1 LEDs

We need one Green LED for this circuit to show when the game is on. The Red LED for indicating cheating is present on the MPR121 touch sensor itself.

6.2 Buzzer

An Active Buzzer Arduino module is used. It produces a single-tone sound when signal is high. The buzzer beeps for different intervals when the game starts or ends.

6.3 Motor

This drives the motor for the motion of the pendulum based on the user inputs. We chose the TowerPro MG995 – Continuous Rotation 360° Metal Gear Servo Motor. It is a digital Servo Motor which receives and processes PWM signal faster and better. It equips sophisticated internal circuitry that provides good torque, holding power, and faster updates in response to external forces. We can use any servo code, hardware or library to control these servos.

Figure 9: Servo Motor

6.4 LED Display

The display shows the time duration for which the game has been on, i.e., the time for which the player kept the pendulum upright. We use the OLED (Organic Light-Emitting Diode) which is a self light-emitting technology composed of a thin, multi-layered organic film placed between an anode and cathode. This 4 pin OLED Display Module can be interfaced with any microcontroller using I2C protocols.

Figure 10: OLED Display

7 State Machine

The system is designed as a state machine and the state machine diagram explaining the functioning of the machine is shown in Fig. 11.

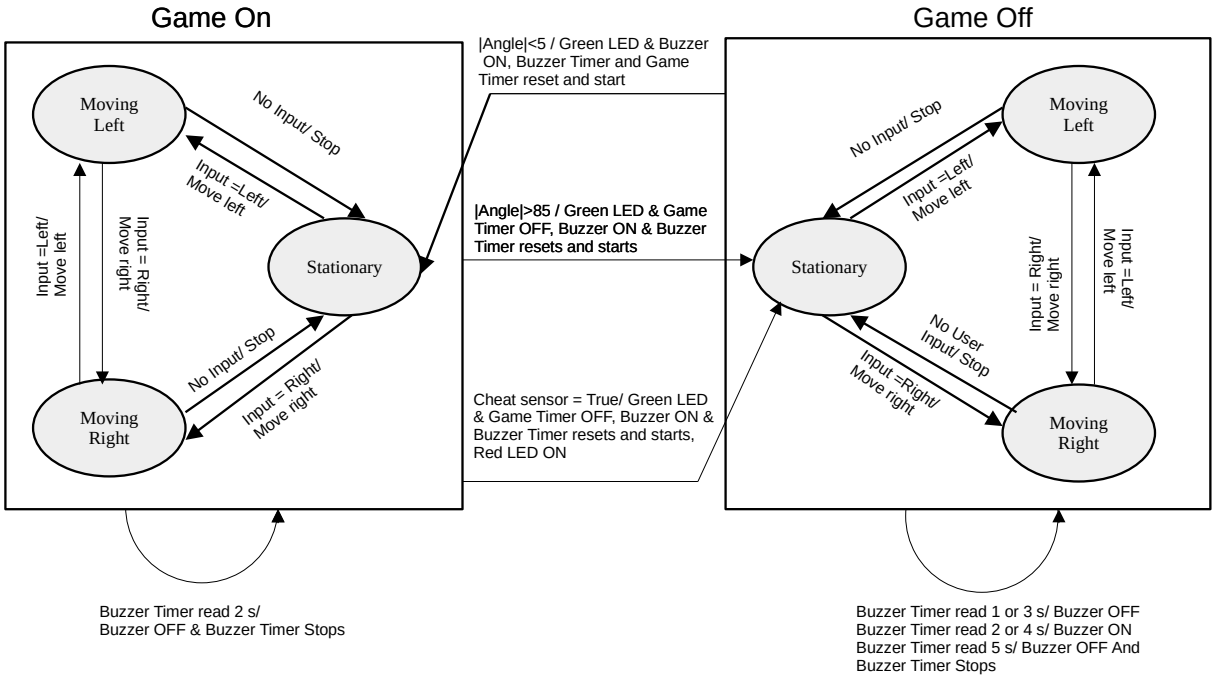

Figure 11: State machine diagram of the inverted pendulum game

The states have been taken to the state of motion of the motor/ pendulum-base since it is the controlled variable in this system. The states are nested in the states - Game On and Game Off to distinguish between the different features of the system in the different conditions.

7.1 Inclusion of the Automated mode

The diagram in Fig. 11 is valid for both manual and automated case. The only difference is that in the manual case, the input comes from the user while in the automated mode the input comes from the microprocessor itself.

The changing of inputs can also be included in the state diagram by nesting the diagram given in Fig. 11 in the states - Manual and Automated. This inclusion in shown in Fig. 12 to create a state diagram for the overall system.

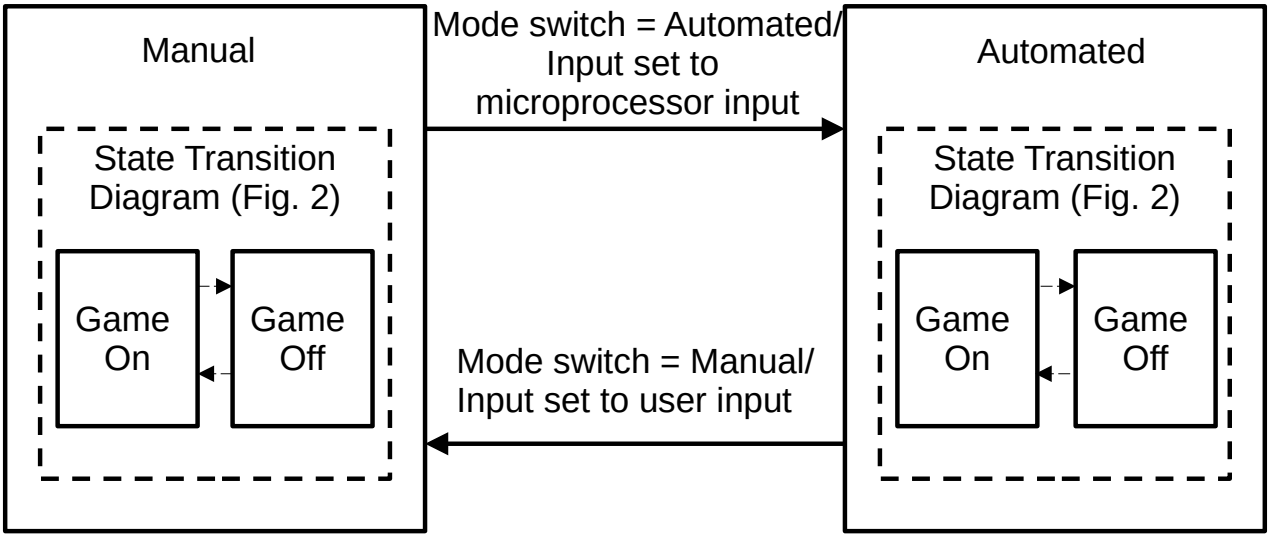

Figure 12: Overall state machine diagram of the inverted pendulum game with manual and Automated modes

8 Circuit Diagram

The circuit diagram is generated using the platform circuit.io.

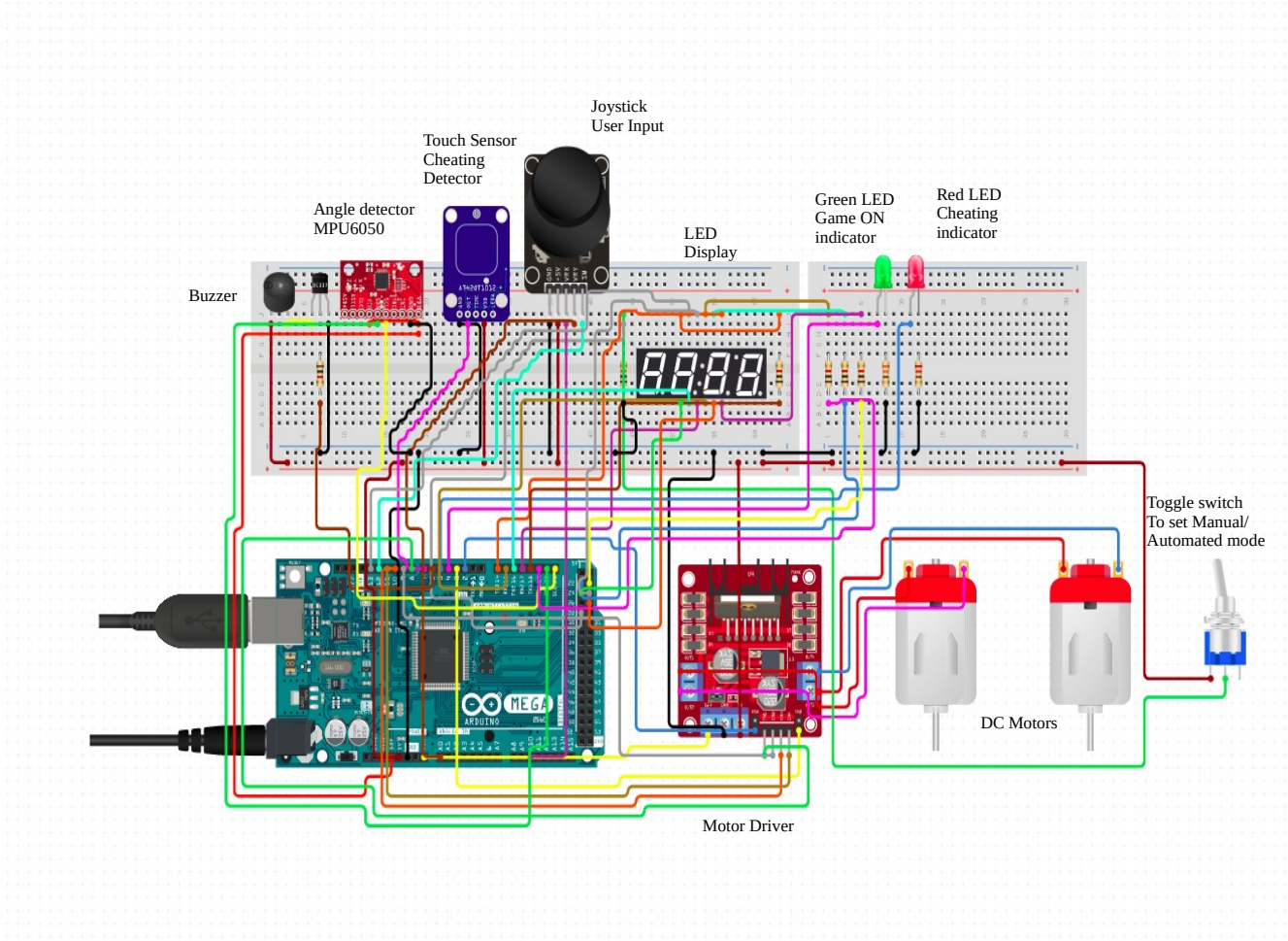

Figure 13: Circuit diagram for the inverted pendulum

9 Bill of Materials

Device	Approximate Cost (in Rupees)
Arduino Uno	800
Joystick	45
MPU6050 Sensor	130
MPR121 Touch Sensor Module	100
Toggle Switch	50
Green LED	5
Buzzer	35
Servo Motor	320
OLED Display	190
Miscellaneous	500
Total Cost	2175