ELEC3042 Minor Project Report

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Overview

In designing the stopwatch, I decided to handle the inputs in the ISR as it was important to the operation of the stopwatch that the inputs be precise. The main state machine handles switching between the three features of the stopwatch, paused, counting, and initial. The main loop is responsible for updating the digits[] array, which is sent to the 7 Segment Display by the sendData() function.

Figure 1 shows the system block diagram and the signals that flow between them.

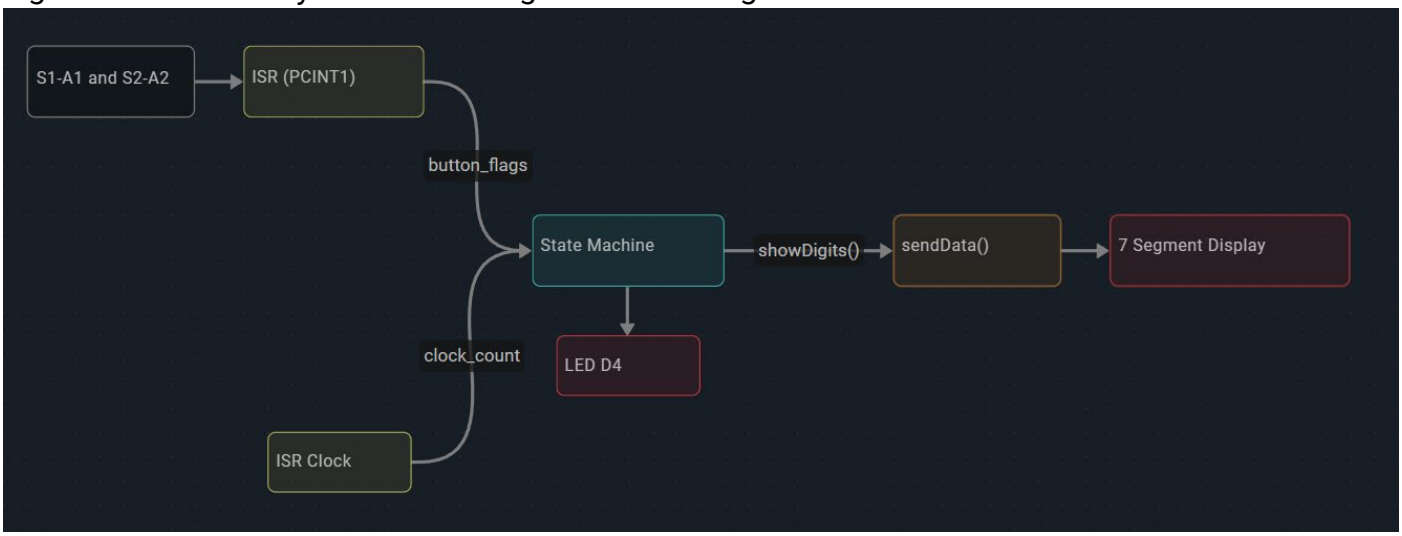


Figure 1: System Block Diagram

System Resources

To keep time in the system I used timer0 in CTC mode to keep time. Timer0 generates an interrupt every millisecond, which increments two variables, clock_count and debounce timer. This saved me having to use two timers to keep track of time for debouncing and for the clock. Changes on the input pins for S1-A1 and S2-A2 (PC1, PC2) generate an interrupt that simultaneously handles debouncing and setting flags that are read by the state machine (button_flags).

```
void timer1Setup (){
    TCCR1A = 0b01000000;                    //CTC Mode
    TCCR1B = 0b00001011;                    // /64 Prescaler
    OCR1A = 2500;                           //Number we are "counting" up to.
    TCNT1 = 0;                              //Number we are "counting" up from.
    ICR1 = 0;                               //Input Capture Register
    TIFR1 = 0b00000000;                     //Timer interrupt flag register
    TIMSK1 = 0b00000010;                    //Timer interrupt mask
}
```

```
void setup() {

    timer1Setup();   //Runs timerSetup

    //DDR - 0 for input - 1 for output
    //PORT - 0 for no pullup - 1 for pullup

    DDRB = 0b00111101;          //Direction Register B - LEDs
    PORTB = 0b00111100;         //PORTB Internal Pullups

    DDRC = 0b00000000;          //Direction Register C - Attached to buttons and the turnpot
    PORTC = 0b00001110;         //PORTC Internal Pullups

    DDRD = 0b10010000;          //Direction Register D - For clocks
    PORTD = 0b00000000;         //PORTD Internal Pullups

    PCMSK1 = 0b00001110;        //Pin Change Mask Register 0
    PCICR = 0b00000010;         //Pin Change Interrupt Control Register

    sei();                      //Enable global interrupts
}
```

PCINT1 Interrupt

PCINT1 is responsible for handling the inputs and interrupting the system to ensure they are read as quickly as possible. The buttons are debounced within the ISR to ensure inputs are only read once. A separate variable, debounce timer, is used to keep time as it makes it much easier to manipulate two separate variables instead of managing the same one.

```
//Interrupt for S1-A1 and S2-A2
ISR(PCINT1_vect) {
    new_button = PINC;                              //Current state of PINC

    uint8_t changed_bits = old_button^new_button;   //Calculate which bits have changed

    if (changed_bits & A1){                         //Check if button change has occurred on A1
        if ((debounce_timer - A1_time)>3){          //If 30 ms has passed
            A1_time = debounce_timer;               //Set A1_time to equal the value of de-bounce (zero it)
            if ((old_button & ~new_button) & A1){   //If there is still a change in A1
                button_flags |= A1;                 //Set flag to high so it can be processed in loop
            }
            old_button = new_button;                //Change the old button state to the new button state
        }

    }
    if (changed_bits & A2){                         //Check if button change has occurred on A1
        if ((debounce_timer - A2_time)>3){          //If 30 ms has passed
            A2_time = debounce_timer;               //Set A2_time to equal the value of de-bounce (zero it)
            if ((old_button & ~new_button) & A2){   //If there is still a change in A2
                button_flags |= A2;                 //Set flag to high so it can be processed in loop
            }
            old_button = new_button;                //Change the old button state to the new button state
        }

    }
}
```

Main State Machine Diagram

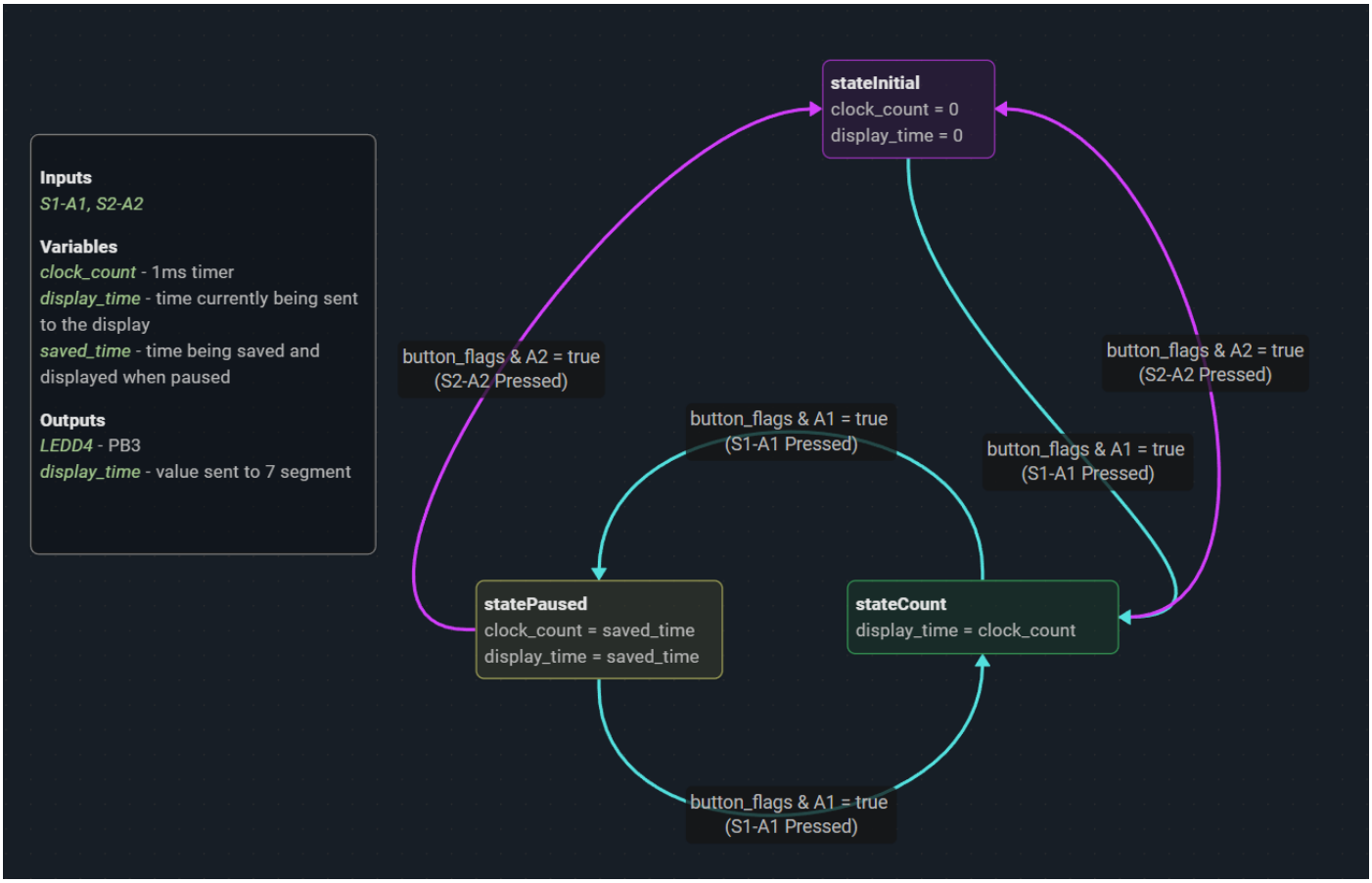


Figure 2: State Machine Diagram

Truth Table

Inputs			curr_state	next_state	Outputs		
clock_count	S1-A1	S2-A2			7 Seg	Counting	LED4
X	1	1	stateInitial	stateInitial	X	0	0
X	1	0	stateInitial	stateInitial	X	0	0
X	0	1	stateInitial	stateCount	X	1	0
X	0	0	stateInitial	stateInitial	X	0	0
X	1	1	stateCount	stateCount	X	1	0
X	1	0	stateCount	stateInitial	X	0	0
X	0	1	stateCount	statePaused	X	0	1
X	0	0	stateCount	stateCount	X	1	0
X	1	1	statePause	statePaused	X	0	1
X	1	0	statePause	stateCount	X	1	0
X	0	1	statePause	stateInitial	X	0	0
X	0	0	statePause	statePaused	X	1	1

Table 1: State Machine truth table

State Machine

The stopwatch is required to have three different functions. An initial state (stateInitial) where the count is zero and the timer isn't incrementing. A counting state (stateCount) which counts upwards from the time initially displayed when S2-A2 is pressed. And a paused state (statePaused) which pauses the timer and turns on LED4. It is also required to resume the count from wherever it was paused. The code for the State Machine is implemented in the main loop.

```
//===Main Loop==//
int main(void) {
    setup();

    cur_state = stateInitial;                       //Set state to Initial off the bat

    while(1) {                                      //Main Loop
        showDigits();                               //Displays digits (0.00.0)
        switch(cur_state){                          //Switch statement

            case stateInitial:                      //Initial State - timer is at 0 and count doesn't increment
                PORTB |= 0b11111111;                //Turn off all LEDs

                clock_count = 0;                    //Reset the time
                display_time = 0;                   //Change the saved time to the current display time (0)

                if(button_flags & A1){                      //If A1 is pressed
                    button_flags = button_flags & ~A1;      //Reset the flag
                    next_state = stateInitial;              //Set the next state to initial
                }
                else{
                    if(button_flags & A2){                  //If A2 is pressed
                        next_state = stateCount;            //Set the next state transition to stateCount
                        button_flags = button_flags & ~A2;  //Reset the flag
                    }
                }
                break;
```

```
            case stateCount:                            //Count State - Timer is counting up from either paused or initial
                PORTB |= 0b11111111;                    //Turn off all LEDs

                display_time = clock_count;             //Assign clock count to display_time - starting the timer from where it was given the previous state

                if(button_flags & A1){                  //If A1 is pressed
                    button_flags = button_flags & ~A1;  //Reset the flag
                    next_state = stateInitial;          //Set the next state transition to stateInitial
                }
                else{
                    if(button_flags & A2){              //If A2 is pressed
                        button_flags = button_flags & ~A2;  //Reset the flag
                        saved_time = display_time;          //Save the value of display_time so it can be resumed later
                        next_state = statePaused;           //Set the next state transition to statePaused

                    }
                    else{
                        next_state = stateCount;            //Return to stateCount
                    }
                }
                break;
```

```
            case statePaused:                           //Pauses count and displays the same value, when start/stop is pressed it resumes
                PORTB &= 0b11111011;                    //Turn on D4 LED

                if (button_flags & A2){                 //If A2 is pressed
                    button_flags = button_flags & ~A2;  //Reset the flag
                    clock_count = saved_time;           //Assign saved_time to clock_count - resuming counting from saved_time
                    next_state = stateCount;            //Set the next state transition to stateCount
                }
                else{
                    next_state = statePaused;           //Otherwise stay in statePaused

                    if (button_flags & A1){             //If A1 is pressed
                        button_flags = button_flags & ~A1;  //Reset the flag
                        next_state = stateInitial;          //Set the next state transition to stateCount
                        clock_count = 0;                    //Reset clock_count to 0
                    }
                    else{
                        if ((button_flags & A2)==1){            //If A2 = button_flags
                            button_flags = button_flags & ~A2;  //Reset the flag
                            next_state = statePaused;           //Set the next state transition to statePaused
                        }

                    }

                }
                break;
                }

    cur_state = next_state;                         //set cur_state to next_state

    digits[0] = ((display_time/10)/600)%10;             //update display_time to change the time displayed on the 7 segment display
    digits[1] = ((display_time/100)%60)/10;
    digits[2] = ((display_time/100)%60)%10;
    digits[3] = (display_time/10)%10;
    showDigits();
}
```

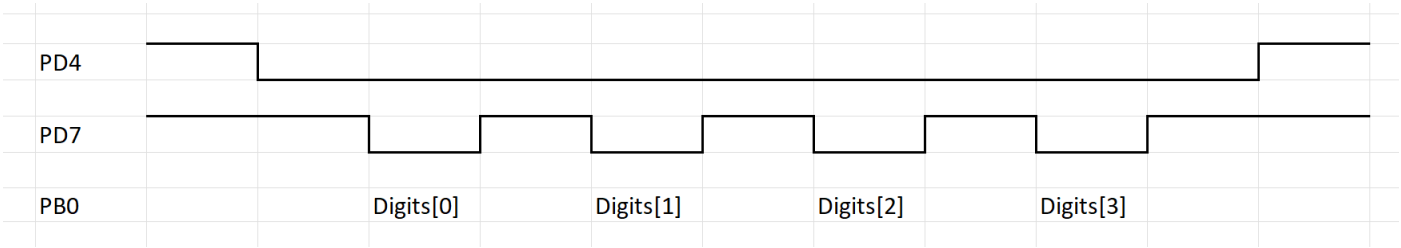
sendData()

sendData() sends the given the segments from segmentMap() and the digits from digits[], sends the requisite signals to the 74HC595 8-bit shift register and latches them to the display.

```
//Sending data to the 7 segment display using segments and digit array as input
void sendData(uint8_t segments, uint8_t digits) {
        PORTD |= _BV(7);                            //Set PD7 High

        for (int i = 0; i < 8; i++){                //Loop 8 times
            PORTD &= ~_BV(7);                       //Set PD7 Low
            if(segments & (0b10000000>>i))          //Compare segments to a mask that shifts based on the value of i
            {
                PORTB |= _BV(0);                    //Set PB0 High
            }
            else
            {
                PORTB &= ~_BV(0);                   //Set PB0 Low
            }
            PORTD |= _BV(7);                        //Set PD7 High
        }
        for(int j = 0; j < 8; j++){                 //Loop 8 times
            PORTD &= ~_BV(7);                       //Set PD7 Low
            if(digits & (0b10000000>>j))
            {
                PORTB |= _BV(0);                    //Set PB0 High
            }
            else
            {
               PORTB &= ~_BV(0);                    //Set PB0 Low
            }
            PORTD = 0b10000000;
        }
         PORTD = 0b10010000;
}
```

The code above follows the general signal graph detailed below.



New data is sent from PB0 to the shift register on the rising edge of PD7. Once all the data is sent PD4 is set to high which latches all the values of

Full Code

```
/*
 * File: MinorProject.c
 * Author: Tyler Johnson
 *
 * Created on 19th March 2022, 4:55 PM
 */

//==============Header files==============
#include <xc.h>
#include <avr/io.h>
#include <avr/interrupt.h>
#define A1 0b00000010                                   //Define variable for A1 pin
#define A2 0b00000100                                   //Define variable for A2 pin

//==== Global Variables and Functions ====
char digits[4];                                         //char array of length 4 - in initial state
volatile uint32_t clock_count = 0;                      //millisecond timer, this is updated every millisecond using a
CTC timer interrupt
volatile uint32_t display_time = 0;                     //Time being displayed
volatile uint32_t saved_time = 0;                       //Time saved (during pause state)

volatile uint32_t A1_time = 0;                          //Time variable for storing time since A1 is pressed first
volatile uint32_t A2_time = 0;                          //Time variable for storing time since A1 is pressed first
volatile uint8_t old_button = 0b00001110;               //Old Button State
volatile uint8_t new_button = 0b00001110;               //New Button State
volatile uint32_t debounce_timer = 0;                   //another millisecond timer running off the same timer
interrupt to keep track of time for debouncing
volatile uint8_t button_flags = 0;                      //Variable for setting button flags

enum STATE {stateInitial, stateCount, statePaused};     //Define each state for the state machine
enum STATE cur_state;                                   //Define a variable to keep track of the current state
enum STATE next_state;                                  //Define a variable to keep track of the state being
transitioned into


//Segment byte maps for numbers 0 to 9
const uint8_t SEGMENT_MAP[] = {
    0xC0, 0xF9, 0xA4, 0xB0, 0x99, 0x92, 0x82, 0xF8, 0X80, 0X90,
// Continuing on for A (10) to F (15)
    0x88, 0x83, 0xC6, 0xA1, 0x86, 0x8E,
// Then blank (16), dash (17)
    0xFF, 0x40
};

//Returns the corresponding segmap value
uint8_t segmentMap(uint8_t value) {
    return SEGMENT_MAP[value];
}
```

```
//Interrupt for S1-A1 and S2-A2
ISR(PCINT1_vect) {
    new_button = PINC;                                  //Current state of PINC

    uint8_t changed_bits = old_button^new_button;       //Calculate which bits have changed

    if (changed_bits & A1){                             //Check if button change has occurred on A1
        if ((debounce_timer - A1_time)>3){              //If 30 ms has passed
            A1_time = debounce_timer;                   //Set A1_time to equal the value of de-bounce (zero it)
            if ((old_button & ~new_button) & A1){       //If there is still a change in A1
                button_flags |= A1;                     //Set flag to high so it can be processed in loop
            }
            old_button = new_button;                    //Change the old button state to the new button state
        }

    }
    if (changed_bits & A2){                             //Check if button change has occurred on A1
        if ((debounce_timer - A2_time)>3){              //If 30 ms has passed
            A2_time = debounce_timer;                   //Set A2_time to equal the value of de-bounce (zero it)
            if ((old_button & ~new_button) & A2){       //If there is still a change in A2
                button_flags |= A2;                     //Set flag to high so it can be processed in loop
            }
            old_button = new_button;                    //Change the old button state to the new button state
        }

    }
}


//Interrupt for timer
ISR(TIMER1_COMPA_vect) {
    clock_count++;                                      //Increment clock count (every millisecond))
    debounce_timer++;                                   //Increment debounce tracking variable
}

void timer1Setup (){
    TCCR1A = 0b01000000;                                //CTC Mode
    TCCR1B = 0b00001011;                                // /64 Prescaler
    OCR1A = 2500;                                       //Number we are "counting" up to.
    TCNT1 = 0;                                          //Number we are "counting" up from.
    ICR1 = 0;                                           //Input Capture Register
    TIFR1 = 0b00000000;                                 //Timer interrupt flag register
    TIMSK1 = 0b00000010;                                //Timer interrupt mask
}

void setup() {

    timer1Setup();   //Runs timerSetup

    //DDR - 0 for input - 1 for output
    //PORT - 0 for no pullup - 1 for pullup

    DDRB = 0b00111101;          //Direction Register B - LEDs
```

```
    PORTB = 0b00111100;         //PORTB Internal Pullups

    DDRC = 0b00000000;          //Direction Register C - Attached to buttons and the turnpot
    PORTC = 0b00001110;         //PORTC Internal Pullups

    DDRD = 0b10010000;          //Direction Register D - For clocks
    PORTD = 0b00000000;         //PORTD Internal Pullups

    PCMSK1 = 0b00001110;        //Pin Change Mask Register 0
    PCICR = 0b00000010;         //Pin Change Interrupt Control Register

    sei();                      //Enable global interrupts
}



//Sending data to the 7 segment display using segments and digit array as input
void sendData(uint8_t segments, uint8_t digits) {
        PORTD |= _BV(7);                            //Set PD7 High

        for (int i = 0; i < 8; i++){                //Loop 8 times
            PORTD &= ~_BV(7);                       //Set PD7 Low
                if(segments & (0b10000000>>i))      //Compare segments to a mask that shifts based on the value of i
                {
                    PORTB |= _BV(0);                //Set PB0 High
                }
                else
                {
                    PORTB &= ~_BV(0);               //Set PB0 Low
                }
            PORTD |= _BV(7);                        //Set PD7 High
        }
        for(int j = 0; j < 8; j++){                 //Loop 8 times
            PORTD &= ~_BV(7);                       //Set PD7 Low
                if(digits & (0b10000000>>j))
                {
                    PORTB |= _BV(0);                //Set PB0 High
                }
                else
                {
                   PORTB &= ~_BV(0);                //Set PB0 Low
                }
            PORTD = 0b10000000;
        }
         PORTD = 0b10010000;
}

//Sends data from digits to the sendData function - which in turn
//displays on the 7 segment
void showDigits() {
    sendData(segmentMap(digits[0]) & 0b01111111, (1<<0));   //Sends data and enables dp
    sendData(segmentMap(digits[1]), (1<<1));
    sendData(segmentMap(digits[2]) & 0b01111111, (1<<2));   //Sends data and enables dp
    sendData(segmentMap(digits[3]), (1<<3));
```

```
    sendData(segmentMap(16), 0);                            // blank the display
}


//===Main Loop==//
int main(void) {
    setup();

    cur_state = stateInitial;                       //Set state to Initial off the bat

    while(1) {                                      //Main Loop
        showDigits();                               //Displays digits (0.00.0)
        switch(cur_state){                          //Switch statement

            case stateInitial:                      //Initial State - timer is at 0 and count doesn't increment
                PORTB |= 0b11111111;                //Turn off all LEDs

                clock_count = 0;                    //Reset the time
                display_time = 0;                   //Change the saved time to the current display time (0)

                if(button_flags & A1){                      //If A1 is pressed
                    button_flags = button_flags & ~A1;      //Reset the flag
                    next_state = stateInitial;              //Set the next state to initial
                }
                else{
                    if(button_flags & A2){                  //If A2 is pressed
                        next_state = stateCount;            //Set the next state transition to stateCount
                        button_flags = button_flags & ~A2;  //Reset the flag
                    }
                }
                break;

            case stateCount:                            //Count State – Timer counting up from paused or initial
                PORTB |= 0b11111111;                    //Turn off all LEDs

                display_time = clock_count;             //Assign clock count to display_time

                if(button_flags & A1){                      //If A1 is pressed
                    button_flags = button_flags & ~A1;      //Reset the flag
                    next_state = stateInitial;              //Set the next state transition to stateInitial
                }
                else{
                    if(button_flags & A2){                  //If A2 is pressed
                        button_flags = button_flags & ~A2;  //Reset the flag
                        saved_time = display_time;          //Save the value of display_time
                        next_state = statePaused;           //Set the next state transition to statePaused

                    }
                    else{
                        next_state = stateCount;            //Return to stateCount
                    }
                }
                break;
```

```
            case statePaused:                               //Pauses count and displays the same value, when
start/stop is pressed it resumes
                PORTB &= 0b11111011;                        //Turn on D4 LED

                if (button_flags & A2){                     //If A2 is pressed
                    button_flags = button_flags & ~A2;      //Reset the flag
                    clock_count = saved_time;               //Assign saved_time to clock_count
                    next_state = stateCount;                //Set the next state transition to stateCount
                }
                else{
                    next_state = statePaused;               //Otherwise stay in statePaused

                    if (button_flags & A1){                 //If A1 is pressed
                        button_flags = button_flags & ~A1;  //Reset the flag
                        next_state = stateInitial;          //Set the next state transition to stateCount
                        clock_count = 0;                    //Reset clock_count to 0
                    }
                    else{
                        if ((button_flags & A2)==1){            //If A2 = button_flags
                            button_flags = button_flags & ~A2;  //Reset the flag
                            next_state = statePaused;           //Set the next state transition to statePaused
                        }

                    }

                }
                break;
                }

        cur_state = next_state;                             //set cur_state to next_state

        //update display_time to change the time displayed on the 7 segment display
        digits[0] = ((display_time/10)/600)%10;
        digits[1] = ((display_time/100)%60)/10;
        digits[2] = ((display_time/100)%60)%10;
        digits[3] = (display_time/10)%10;
        showDigits();
    }
}
```