Autonomous Ping Pong Collection Robot

EECS 373, Intro. to Embedded System Design Project

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Overview

- Table Tennis Multi-ball Training
- Collecting balls is tiring and time-wasting
- Avoid body pain caused by frequently bending down

Main Features

- Collector: 1 servo, 3D printed components
- Motion: 4 mecanum wheels, motors (H-Bridge, PWM)
- CV: recognition & localization
- Inter-Controller UART Communication
- Manual mode: debugging and playing with N64 Controller
- Displaying statistics: LCD, I2C

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Collector Design

- roller with rubber bands to "catch" and reserve balls
- motor free, rolled by friction
- servo to add pressure or raise the roller up

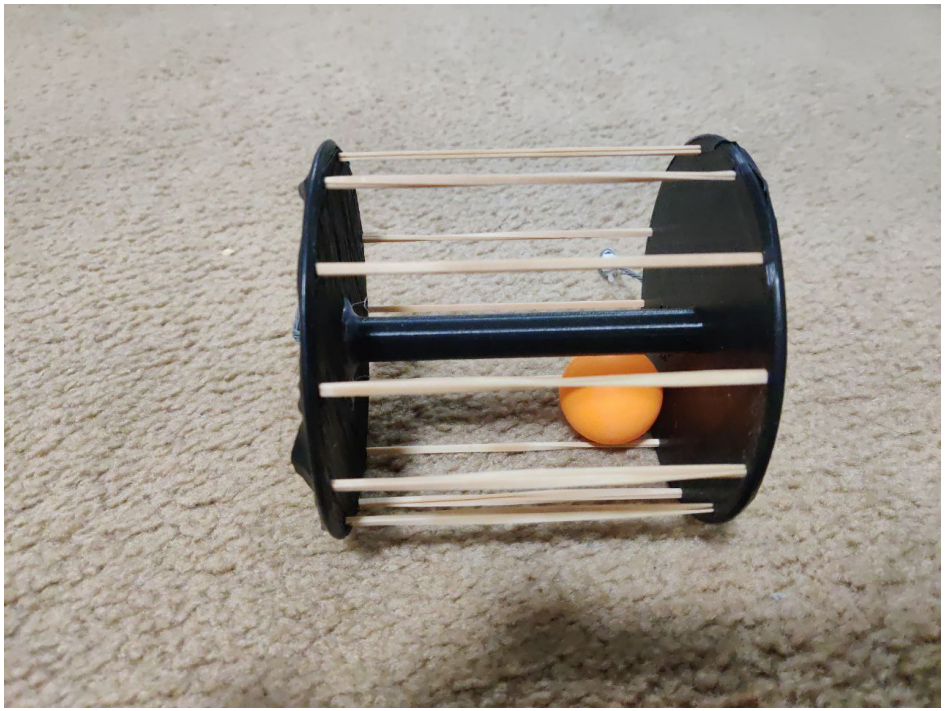
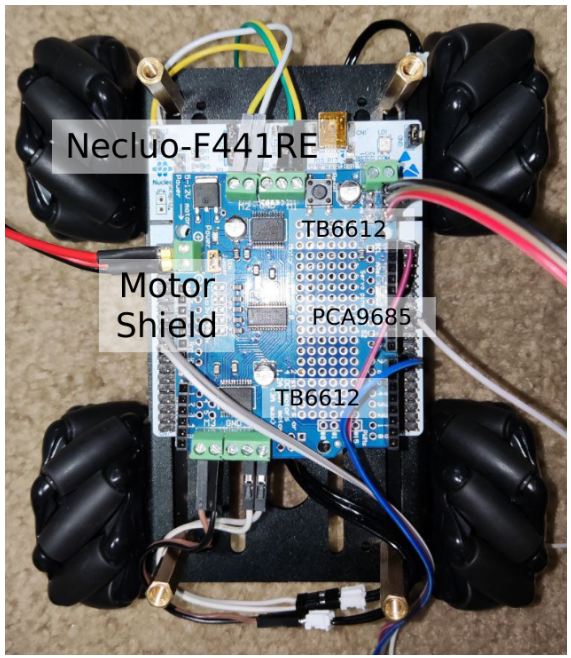


Figure: Roller with a ball

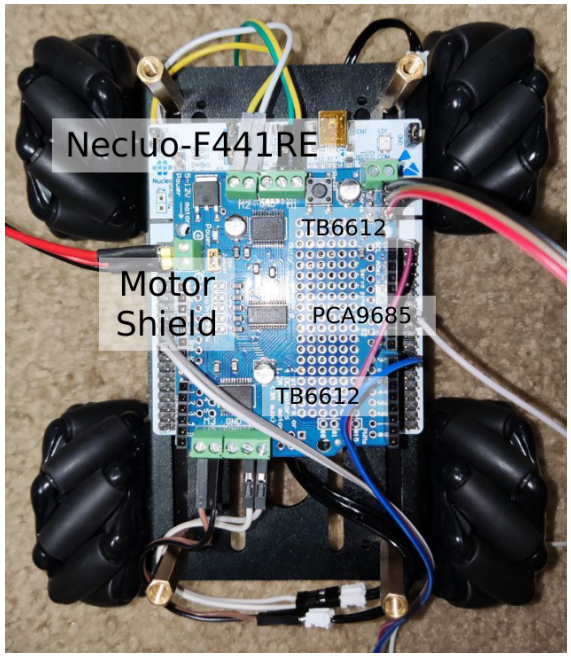
Motors and Servos

- Task
  - Control totally 4 motors and 1 servo
- Solution
  - Motor Shield
    - 1 * PCA9685 I2C PWM Controller
    - 2 * TB6612 DC drivers
  - Send command via I2C to set PWM Controller, which controls motor drivers and servos



Motors and Servos

- Challenge
  - Datasheets available for PWM Controller and DC drivers, but no datasheet for the Motor Shield
- Solution
  - Refer to Arduino library provided by MotorShield manufacturer
  - Use logic analyzer to debug I2C transmission



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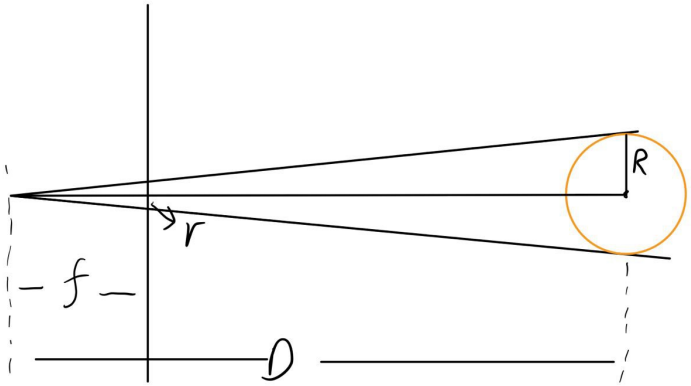
Ball Recognition

- assume ping-pong ball to be yellow
- convert to HSV color space for easy color extraction
- extract a range of color from the frame that may be the ball
- find contours on the extracted mask
- for big contours, calculate the mininum enclosing circle to be the ball

Localization

- We know the actual radius of the ball R, focal length f, and size of the ball on the frame r
- The distance of the ball d can be calculated as $d = \frac{fR}{r}$
- Thus the position of the ball in camera coordinate can be calculated
- Match the balls with previous frame using ICP algorithm and get the camera motion



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Inter-Controller Communication

- Recognition and Localization computed on Raspberry Pi, need to give control information to STM32 board
- Serial UART communication is used
- Task: defining an efficient and stable communication protocol
- Solution:
  - 2 0xFF to start transaction
  - 1 Header byte to indicate device to operate
  - 1 or 2 data byte(s) depending on device type
  - 2 0xFF to end transaction
  - slave device transmit 1 byte to ensure completion

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N64 Controller Protocol

- 1-wire, half-duplex serial protocol
- OD/OC circuit with pull-up resistor required to avoid multi-driver issue
- 3-4 μs per bit transaction, and at least 2x sampling rate for receiver, which is sub-megahertz
- little endian but MSB first instead of LSB first

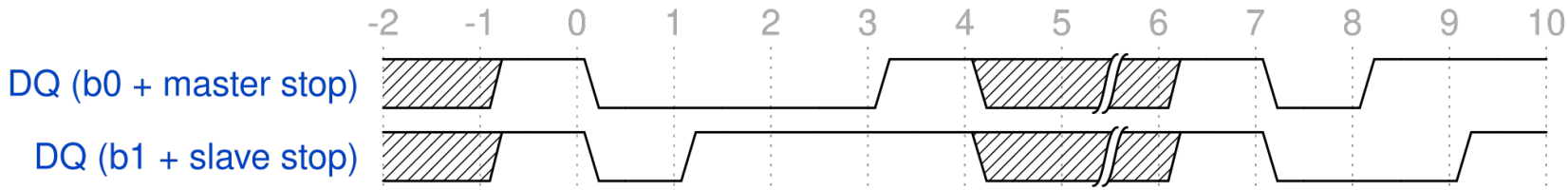

Figure: Timing Diagram of Bit Transaction

- **What is the major difficulty in implementation?**

Interfacing Challenges

- Welcome to real-time programming!
- **Time is precious resource!!!**
  - OD/OC design makes rising edge slow
  - internal pull-up resistor with 40kΩ is catastrophic
  - need microsecond level delay, but timer MMIO is slow
  - interrupts/buffering cannot be tolerated
  - memory accesses cannot be tolerated
  - function calls with stack pushes/branching cannot be tolerated
- Solutions:
  - use small external pull-up resistor (4.7kΩ)
  - implement microsecond delay by counting instructions
  - RAII CPU mutex locks interrupts for atomicity
  - use very few variables inside critical section
  - force function calls to be inline inside critical section

A New Issue: Mix Compiling C/C++

- As stated before, in order to meet the timing requirements, we would like to have RAII mutexes and inline functions.
- This cannot be easily achieved using C, and therefore C++ is used to implement these features.
- **However, C/C++ name function labels differently in assembly:**
  - C: `int f(int);` compiles to `f:`
  - C++: `int f(int);` compiles to `_Z1fi:`
  - Need `extern "C"` syntax to tell the compiler about C functions
- More on this topic: Check out name mangling on the Internet

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Setting Up LCD

- Challenges: sending 8-bit data/command through 4-bit channel
- Solutions:
  - EN falling edge sensitive, 2 transactions per byte
  - Cut the data in Upper 4-bit and Lower 4-bit
  - Configure data and send

```
void LCD::send(uint8_t byte, bool type)
{
        uint8_t encoded[4] = {0};
        uint8_t byteHigh = byte & 0xF0;
        uint8_t byteLow = (byte & 0x0F) << 4;
        encoded[0] = byteHigh | enableHigh | (type & 0b1);
        encoded[1] = byteHigh | enableLow | (type & 0b1);
        encoded[2] = byteLow | enableHigh | (type & 0b1);
        encoded[3] = byteLow | enableLow | (type & 0b1);
        HAL_I2C_Master_Transmit(&i2c, address, encoded, 4, HAL_MAX_DELAY);
}
```

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Next Step

- Assembly all the parts
- Set up simulation environment
- Conduct all-around testing

Thank you!

Q & A