FPGA Ball and Plate Proposal

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Introduction

Our project is an FPGA-controlled ball and plate system. The plate is a 4-wire resistive touch panel mounted atop a servo-actuated Stewart platform that will be managed by the Nexys 4 development board. The FPGA will command the motion of the platform to keep a steel ball stable at a specific point on the plate.

The touch panel is interfaced through an integrated circuit that interprets the ball's coordinates from analog voltages and communicates them to the FPGA. The system will take user input from an analog joystick.

Operation

The system will have two modes of operation, feedback-controlled and manual control, toggled by an FSM.

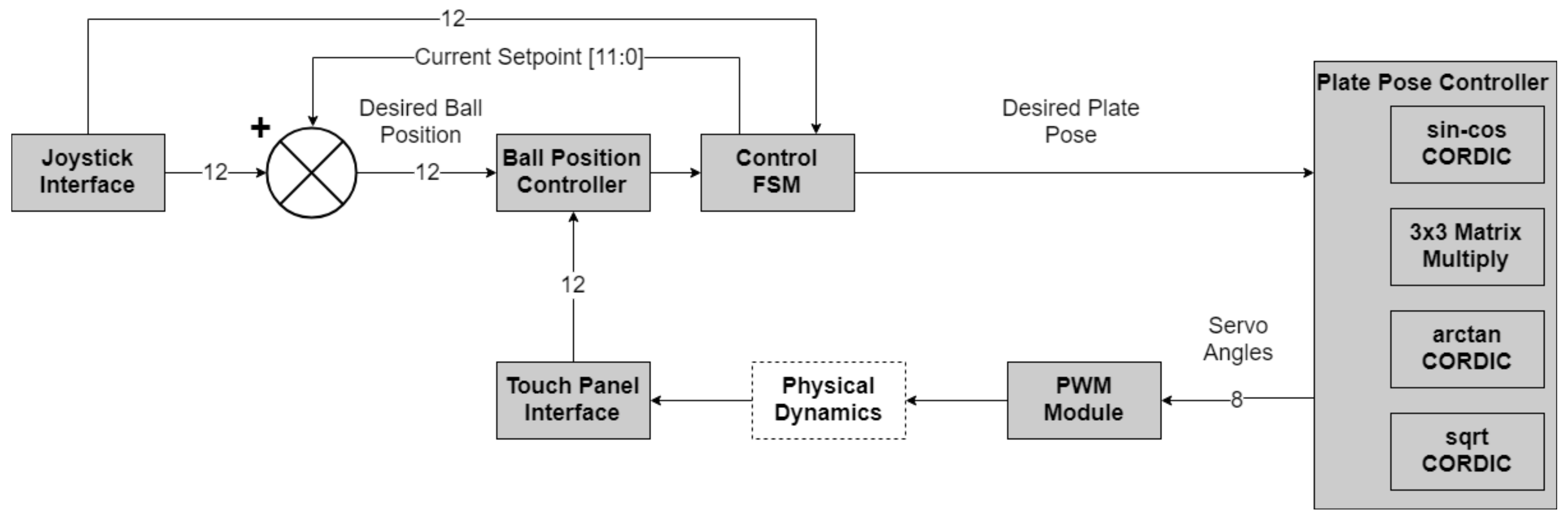
Under feedback control, the system will accept coordinates from the touch panel IC, compare them against a desired setpoint, command a new plate orientation in order to shrink their difference, and then drive the servos to realize it. Manipulating the joystick will add an offset to the current desired setpoint.

Under manual control, the joystick axes will directly adjust the platform roll and pitch.

Hardware

The Stewart platform itself will have to be fabricated and assembled. Most of the necessary components have already been acquired or are available through EDS services. We plan to construct the platform using pieces laser cut from acrylic and fashion the platform legs using standard threaded rods and ends. Items to be purchased are a resistive touch panel, a steel ball, and the fasteners necessary to assembly the platform legs. Rotation of the plate will be limited by the rod ends to 30 degrees from horizontal.

The operation of the platform and the touch panel will be first confirmed by controlling it with an Arduino Uno.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Current Setpoint [11:0]
Desired Ball Position
Desired Plate Pose
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Joystick Interface
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Ball Position Controller
Control FSM
Plate Pose Controller
sin-cos CORDIC
3x3 Matrix Multiply
arctan CORDIC
sqrt CORDIC
12
Servo Angles
8
Touch Panel Interface
Physical Dynamics
PWM Module

Modules

Touch Panel Interface

Input(s): MOSI, CS, SCLK, clock
Output(s): MISO, panel coordinates

The touch panel IC converts the analog potentiometer values into 12-bit readings of the plate coordinates up to a rate of ?kHz, giving us a maximal mm resolution. This information is communicated over an SPI bus.

Joystick Interface

Input(s): Analog in, clock
Output(s): Potentiometer readings

The joystick interface will use the ADC capability on the Nexys 4 to sample both axis potentiometers, resolved to 12-bits to match the bit depth of the touch-panel.

Ball Position Controller

Input(s): Desired coordinates, actual coordinates, feedback enable, clock
Output(s): Roll and pitch angles

Control of the ball position on the plate will actually be achieved by two feedback controllers operating in parallel, one for each axis. The axial errors between the desired and actual position will be used to generate new pitch and roll targets for the platform.

Plate Pose Controller

Input(s): Plate pose (X, Y, Z, roll, pitch, yaw), clock
Output(s): Individual servo angles

Given a desired plate position and orientation, this module calculates the servo angles required to achieve it. This module can be broken down into two stages:

1. First, given a desired pose, calculate how far each plate joint must be from its corresponding base joint.
2. Calculate the servo angles that put the plate joints in these positions.

The first stage will calculate the these distances with straightforward matrix operations. Translation is just an addition. Rotations involve a matrix product with each Euler angle. Achieving this will involve a small number of CORDIC blocks to calculate all sin and cos pairs. Basic trigonometric identities enable replacing all product terms within the rotation matrix product with bit-shifted sums.

The second stage will require arctan and square root CORDIC blocks to translate this distance into a servo angle. Because our servos are probably not terribly accurate (we expect at most to the nearest degree), this angle will be rounded to an 8-bit value.

3x3 Matrix Multiply

Input(s): Matrix terms, clock
Output(s): Product

Even with mathematical simplifications, the inverse kinematics calculations still require one 3x3 matrix multiplication per servo; we're abstracting this operation to a separate module.

Control FSM

Inputs(s): Joystick values, ball position controller outputs, clock, toggle switch
Outputs(s): Desired plate pose, feedback enable, current setpoint

This state machine will handle the input to the plate pose controller to produce manual and feedback control regimes. In both modes, the plate translation and yaw will be set to 0. The toggling will swap the roll and pitch source between the joystick and the ball position controller. It will keep track of the current setpoint.

Servo PWM Interface

Input(s): Servo angles, clock
Output(s): Pulse

Our servos are driven from a 500Hz square wave. This module will take an angle command produced by the plate orientation controller and modulate it into the appropriate width pulse between one and two milliseconds to drive a servo.

Stretch Goals

If time permits, several expansion features will be considered.

1. Make the ball to follow a certain trajectory.
2. Manually control the platform by having it follow the movement of an IMU, possibly in all six degrees of freedom.