Agile Robot Project Proposal

Overview

Using AI models, robots are now able to perform complex tasks by learning to imitate humans [Stanford HumanPlus]. In this project, we will use high speed AI models to demonstrate what an agile robot can do with human level hand-eye coordination. The high-speed AI models in this project run on FPGA silicon devices and can achieve 100 frames per second with 20 milliseconds latency, opening the possibility of a robot with superhuman reaction time. Ultimately, we would like to build a humanoid robot that can juggle multiple objects, or dance with a partner.

As a first step, this proposal describes an automated marble maze robot as shown in Figure 1. The marble maze is a table with holes which can be independently tilted in two dimensions. The objective is to roll a steel marble along a path by continuously adjusting the X and Y table tilt, without the marble falling into a hole. This task requires fast reaction time since the marble can accelerate quickly.

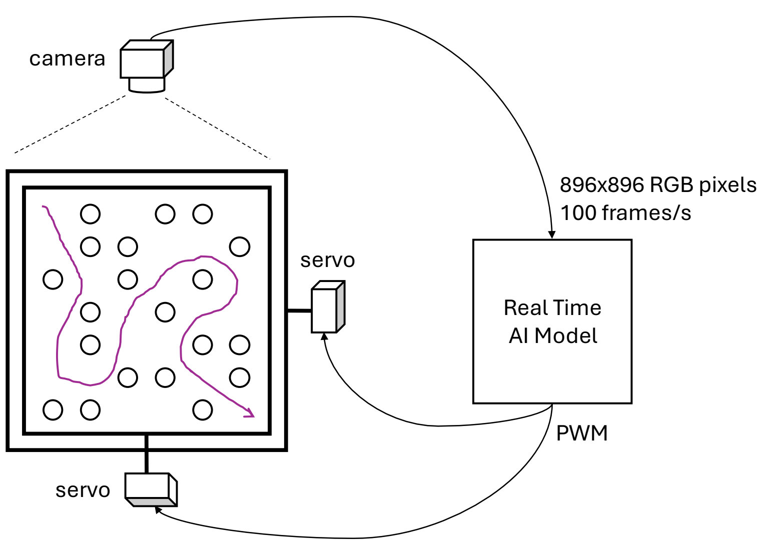

Figure 1

The overall approach requires two main steps. The first step is to build the hardware and software robot platform, which requires a combination of mechanical, servo, image sensor, FPGA Verilog hardware, embedded ARM software, and user interface software components as shown in Figure 2. The robot will work in two modes, “human shadowing” and “imitation replay”. In human shadowing mode, a person manually controls the table using a pair of potentiometers and analog PWM servo controllers. Simultaneously, data is collected which consists of overhead images of the table and the corresponding human controlled XY servo pose values with time stamps. In step two of the project, human shadowing mode is used to collect a dataset with hundreds of examples from multiple human players. This dataset can be used to train the AI models, which are then deployed using imitation replay mode. In imitation mode, the XY tilt servo motors are automatically controlled using the AI models. The AI model will attempt to roll the marble toward the goal, using the camera to guide the XY servo movements.

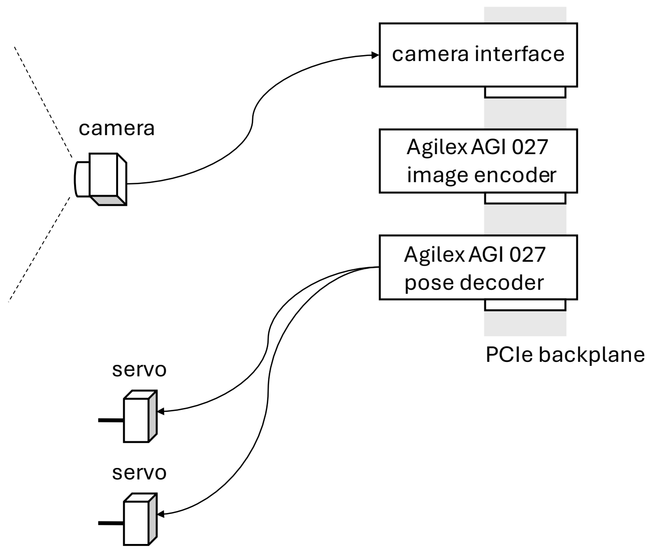

Figure 2

Project Plan

The following steps form the outline of a project plan.

1. Build robot hardware platform
    a. Precision XY table with two servo motors
    b. Servo controller with shadow and replay modes
    c. PCIe backplane, power supply, and ATX enclosure
    d. Camera with overhead mount and PCIe interface board
    e. Agilex 027 FPGA PCIe boards
2. Design, simulate and compile FPGA Verilog code
    a. PCIe camera interface
    b. IE120R image encoder
    c. feature trajectory storage using DDR
    d. DX120P pose decoder
    e. PWM servo interface
3. Design, build and test embedded ARM code for Agilex
    a. Camera driver
    b. Servo driver
    c. IE120R driver
    d. DX120P driver
4. Build Python/RoS user interface
    a. Data collection application using shadow mode

b. Imitation replay application

5. Using #1-4, collect a new dataset consisting of sequences of tuples (overhead image, servo pose) using human examples
6. Train IE120R and DX120P models using #5
7. Test trained models and refine

Material and Equipment

Table 1 lists the main budget items. There are also miscellaneous mechanical components, tripods and camera mount, enclosure, etc which will be required.

Item	Budget	Description
Industrial RGB camera	$1K	RGB camera, 896x896 ROI, 100 frames/s
Agilex FPGA boards	2@$10K	Agilex AGI027 PCIe boards (encoder+decoder)
PCIe backplane	$1K	Peer to peer PCIe backplane
GPU workstation	$10K	Xeon workstation, 256GB RAM, RTX4090 GPU

Table 1

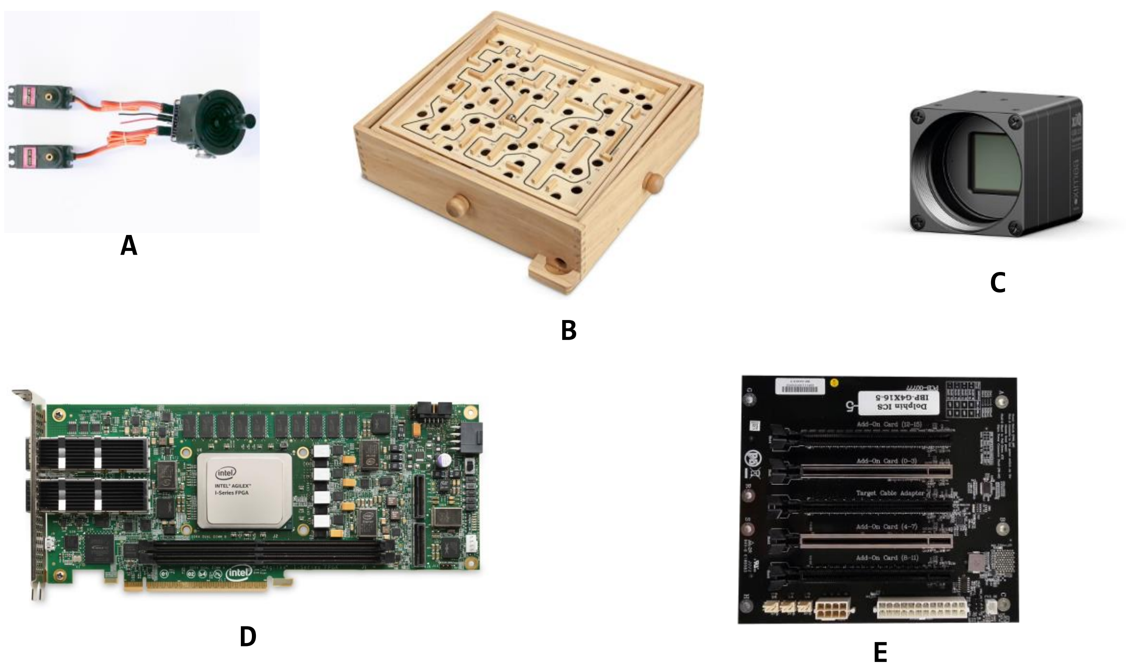

Figure 3

The items in Figure 3 are referenced in Table 2, and show some of the key components needed for the project.

Item	Link
A	Analog servo controller for shadowing mode
B	Marble maze table
C	XIMEA industrial RGB camera

D	Agilex FPGA development board
E	PCIe backplane

Table 2