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TBRR : Tennis Ball Retriever Robot Based on FPGA

Lu Haolin, Lin Qi
Xi`an University of Posts & Telecommunications
Shanxi Province

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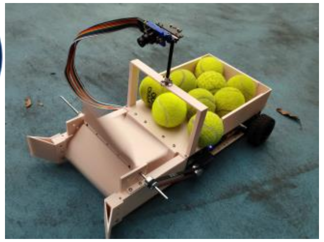

On board test by AMD ZYNQ7010

INTRODUCTION

Picking up tennis balls is a tedious and labor-intensive task for tennis trainers, as they are often scattered over a wide area, and their large size makes the process time-consuming. Currently, no robot on the market addresses these challenges. Our ball-retrieving robot is designed to solve these issues by incorporating tennis ball recognition, positioning, automatic collection, and human-machine interaction.

Tennis Ball Recognition and Positioning:
The FPGA accelerates image processing by converting RGB images to YCbCr format. This is followed by binarization to separate the ball from the background, edge detection to identify the contours of the ball, and morphological operations like erosion and dilation to refine its position. These tasks are performed in parallel, enabling real-time ball recognition and precise positioning. Image data is transferred to the processing system using the **Video In to AXI4-Stream IP core** provided by Xilinx, allowing efficient data flow between the image capture module and the ARM processor for further processing.

Autonomous Movement and Collection:
The ARM processor analyzes the processed image data to determine the ball's position and generates control signals. These signals guide the robot autonomously to the ball's location and manage its collection process.

Human-Machine Interaction:
A Bluetooth module enables real-time communication with a mobile device, allowing users to send control commands for manual operation or adjustments to the robot's tasks.

CREATIVE DESING

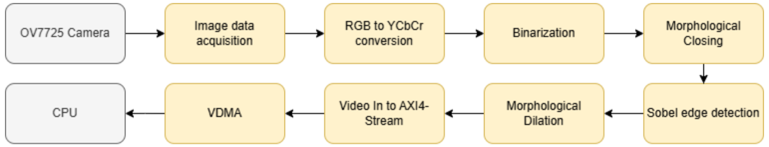

Image Acquisition and Processing

In automatic ball retrieval mode, the CPU configures the OV7725 image sensor using the SCCB protocol, setting parameters like binarization and edge detection thresholds. The OV7725 captures 24-bit RGB888 images at VGA resolution, which are transmitted to the ZYNQ platform via a high-speed interface. The RGB data is converted to YCbCr for binarization and threshold adjustment. Image processing, including morphological closing, Sobel edge detection, and dilation, extracts the ball's edges for localization. The processed data is transmitted in AXI4-Stream format to the VDMA module, where it is stored and retrieved from DDR3 memory for further processing.

Custom Morphological Operation IP Core:
The 24-bit YCbCr formatted image data is stored in a 5×5 RAM array, where efficient erosion and dilation operations are performed using parallel computation. This design significantly improves the processing speed and image frame rate of morphological operations by leveraging multi-line parallel processing technology. On this basis, morphological operation IP cores such as closing and opening operations have been developed, optimizing the detail handling capability in the image analysis process.

RESULT

The system's frame rate performance test shows approximately 66 detections per second, meeting the requirement for real-time tracking of the tennis ball. The ball pickup mechanism effectively collects nearly all dropped balls within the robot's field of view, with a maximum storage capacity of 9 balls. If the balls go out of view, the robot switches to manual control via Bluetooth to move closer to the ball and resumes automatic ball pickup.

The Bluetooth communication response time was measured at around 200 milliseconds, ensuring smooth remote operation. Finally, the system's power consumption was measured at 9.51W, with stable performance, meeting the technical requirements and ensuring the robot's stability and endurance over time.

Maximum System Power Consumption	9.51W
Bluetooth Communication Range	> 15m
Bluetooth Response Time	< 200ms
Maximum Ball Storage Capacity	9
Image Processing Frame Rate	> 60hz
Detection Range	20cm-1800cm