ECE 445

SENIOR DESIGN LABORATORY

PROJECT PROPOSAL

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# FPGA-based object tracking, obstacle avoidance, and voice-activated trolley

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**Team #445**

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# 1 Introduction

## 1.1 Problem

Nowadays, the development of electric vehicles today has become a trend. At the same time more and more new energy vehicle startups like to equip their cars with intelligent systems. However, existing SOCs are always based on non-real-time operating systems and cannot meet the real-time and safety of the in-vehicle system. Common systems which are based on CPU + GPU tend to have high energy consumption [1], which will have a negative impact on the endurance of the vehicle. Therefore, it is necessary to design a system with low energy consumption and high real-time performance.

## 1.2 Solution

In order to achieve low energy consumption and high real-time performance, our solution is to design a specific system to control our trolley based on FPGA. The latency of some FPGA-based designs can be deterministic. Besides, FPGAs are typically more energy efficient than other platforms except for ASICs, which usually have higher Non-Recurring Engineering (NRE) costs [1]. For neural network inference accelerators, FPGA implementations can be up to 10x more energy efficient than GPU ones [2].

## 1.3 Visual Aid

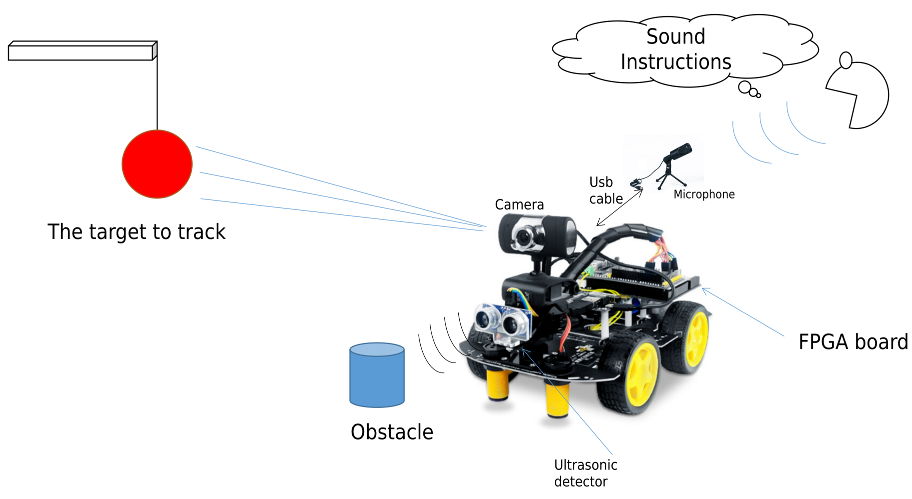


Figure 1: A pictorial representation of project

# 2 Design

## 2.1 Block Diagram

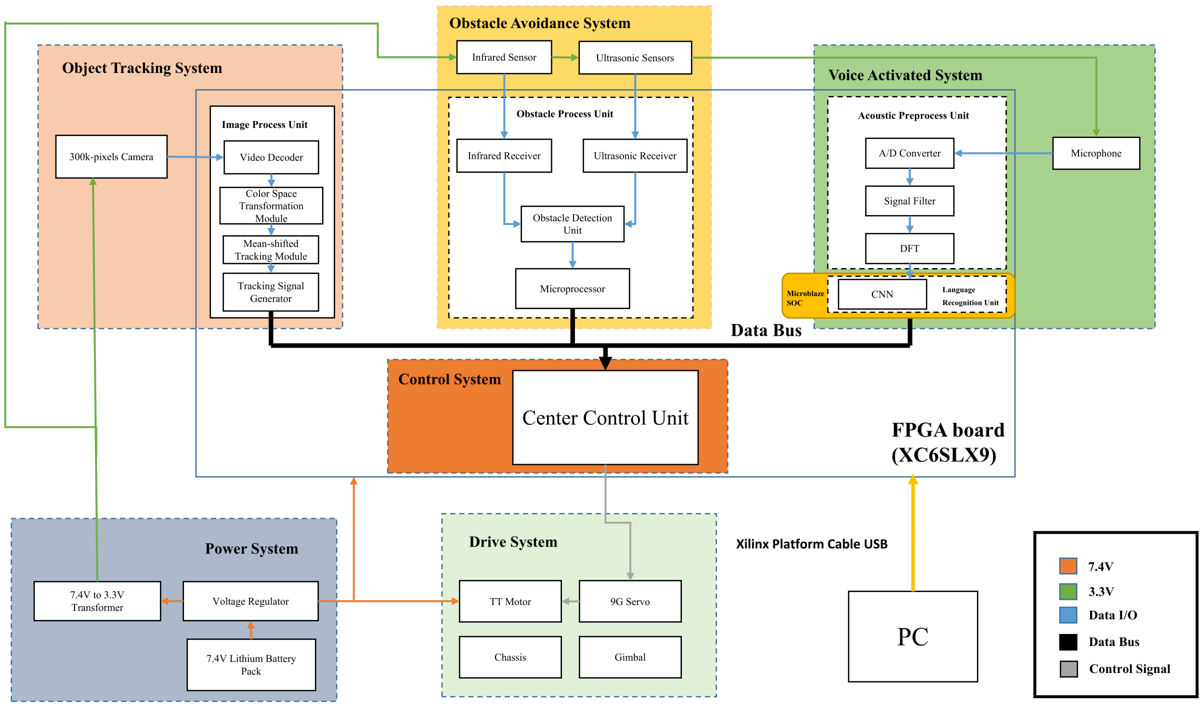


Figure 2: Block Diagram of System

## 2.2 System Overview

- The Control subsystem consists of a central control unit in FPGA. It receives control signals from the Object Tracking subsystem, Obstacle Avoidance subsystem, and Voice-Activated subsystem to produce the required signals output to the Drive subsystem.
- The Object Tracking subsystem consists of a 300k-pixel camera and image process unit in FPGA. It captures the image with a camera and sends control signals to the Control subsystem.
- The Obstacle Avoidance subsystem consists of ultrasonic sensors, infrared sensors and obstacle process unit in FPGA. It detects obstacles with sensors and sends control signals to the Control subsystem.
- The Voice-Activated subsystem consists of a microphone and acoustic process unit in FPGA. It receives sounds with the microphone and sends control signals to the Control subsystem.
- The Drive subsystem consists of a TT motor, a 9G servo, a gimbal and a chassis. It receives control signals from the Control subsystem to adjust the output of the TT

motor and 9G servo to drive the car.

- The Power subsystem consists of a 7.4V lithium battery pack, voltage regulator and 7.4V to 3.3V transformer. It acts as the power supply of all other subsystems.

## 2.3 Subsystems Requirements

### 2.3.1 Control Subsystem

The Control subsystem is responsible for processing real-time data from other subsystems and producing signals to control the movement of the trolley. The control signals are passed through an FPGA port to the Drive subsystem to control the speed of the electric motors and the direction of the servo. The Control subsystem connects with the Object Tracking subsystem, Obstacle Avoidance subsystem, and Voice-Activated subsystem with the data bus, and the Control subsystem should define a priority and logic to handle the control signals from these three trajectory planning subsystems to avoid conflict. The Control subsystem should react in a short time to ensure safety.

### 2.3.2 Object Tracking subsystem

The Object Tracking subsystem uses a camera to capture images in front of the trolley and sends the image to the FPGA through USB. The image process unit processes the image with a video decoder, color space transformation module and mean-shift tracking module[3], then the tracking signal generator will generate suitable control signals of the speed of motors and the direction of the servo, and the trolley will move toward the object. Control signals are passed on to the Control subsystem.

### 2.3.3 Obstacle Avoidance subsystem

The Obstacle Avoidance subsystem uses ultrasonic sensors and infrared sensors to detect obstacles in the path of the trolley. The sensors are connected to the obstacle process unit in FPGA with wires. If the obstacle process unit detects the signal of the obstacle, it will produce controls signals to of the speed of motors and the direction of the servo to avoid the obstacle, so the trolley will not collide with the obstacle. The control signals are passed on to the Control subsystem.

### 2.3.4 Voice-Activated subsystem

The Voice-Activated subsystem is responsible for recognizing specific natural language instructions and acting accordingly. The voice signals from the microphone will be processed by the A/D converter, signal filter and DFT, then passed to CNN[4]. A CNN network is built on MicroBlaze SOC to reduce latency and achieve high recognition accuracy. The subsystem has at least 4 instructions: move forward, move backward, turn left and turn right. The Voice-Activated subsystem connects with the Trolley Movement Control subsystem to produce the required signals of the speed of motors and the direction of the servo for the movement of the trolley.

#### 2.3.5 Drive system

The Drive subsystem should be able to respond to user inputs and system commands within 100ms. The drive system should be able to operate continuously without overheating or experiencing mechanical failure. The TT motor should be able to move the trolley smoothly and accurately in different directions, such as forward, backward, left, and right. The 9G servo should be able to adjust the angle of the gimbal smoothly and accurately in response to servo control signals. The chassis should be designed to support the weight of the entire system and allow for smooth movement of the trolley, with a minimum weight capacity of 1kg. The gimbal should be able to support the camera module and adjust its position smoothly and accurately in response to servo control signals.

#### 2.3.6 Power System

The Power subsystem should be able to supply a stable voltage of 7.4V to power the FPGA and Drive system and supply a stable voltage of 3.3V to power the camera, sensors and microphone. The current should also be stable. The voltage regulator should be able to adjust the voltage so that the cameras, sensors and motors work well. The power system should include overcurrent, overvoltage, and undervoltage protection to prevent damage to components in the event of a power surge or other electrical anomaly.

### 2.4 Tolerance Analysis

One aspect of the design that may pose a risk to the successful completion of the project is the accuracy of the obstacle avoidance systems. To demonstrate the feasibility of this component, a mathematical analysis is provided below.

The mass of the whole vehicle is 850g. The target speed is $0.3m/s$, and the max acceleration is above $1m/s^2$, so it should able to stop in 0.15m. While the ultrasonic sensor can easily detect the obstacle 0.15m far away, so it is reasonable that the obstacle avoidance system works well.

## 3 Ethics and Safety

We will adhere to ethical principles outlined by IEEE and/or ACM, and appropriate safety features should be included in the design to ensure that the project is developed in a responsible and safe manner.

The project may involve the collection and storage of sensitive information, such as voice data or images. It is important to ensure that this information is kept confidential and that appropriate measures are taken to protect it from unauthorized access or disclosure. We will carefully store and encrypt the data and delete it after the tests finish.

In terms of safety and regulatory standards, we will adhere to relevant regulations, industry standards, and campus policies. This includes ensuring that the trolley and its components are designed and manufactured in a safe manner and that appropriate safety features are included, such as emergency stop and obstacle detection sensors.

# References


[1] Y.-H. Chen, T.-J. Yang, J. Emer, and V. Sze, "Understanding the limitations of existing energy-efficient design approaches for deep neural networks,"

[2] D. Castells-Rufas, V. Ngo, J. Borrego-Carazo, *et al.*, "A survey of FPGA-based vision systems for autonomous cars," *IEEE Access*, vol. 10, pp. 132 525–132 563, 2022, Conference Name: IEEE Access, ISSN: 2169-3536. DOI: 10.1109/ACCESS.2022.3230282.

[3] X. Lu, D. Ren, and S. Yu, "FPGA-based real-time object tracking for mobile robot," in *2010 International Conference on Audio, Language and Image Processing*, Nov. 2010, pp. 1657–1662. DOI: 10.1109/ICALIP.2010.5685091.

[4] H. Hu, J. Li, C. Wu, X. Li, and Y. Chen, "Design and implementation of intelligent speech recognition system based on FPGA," *Journal of Physics: Conference Series*, vol. 2171, no. 1, p. 012 010, Jan. 2022, Publisher: IOP Publishing, ISSN: 1742-6596. DOI: 10.1088/1742-6596/2171/1/012010. [Online]. Available: https://dx.doi.org/10.1088/1742-6596/2171/1/012010 (visited on 03/08/2023).