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Programme	<i>Engineering</i>
Year of Study	<i>2nd year</i>
Research Project Title	<i>Investigating the Use of Field-Programmable Gate Arrays (FPGAs) for Object Detection in High-Speed Autonomous Navigation</i>
Proposed Supervisor(s)	<i>Dr. Shreejith Shanker, Department of Electronic and Electrical Engineering</i>

Research Project Proposal (1000 words max.)

Introduction

For my research proposal, I would like to experiment with the potential use of FPGAs for object detection in highspeed autonomous navigation. Object detection and recognition is a vital component for many autonomous navigation systems, this includes detecting things like cones, people, road markings, etc. Especially in the context of high speed vehicles, rapid object detection is essential, however processing the images requires quite a bit of computational power in order to do so quickly.

A Field-Programmable Gate Array (FPGA) is a useful type of device which, unlike standard CPUs or GPUs, can redesign logic blocks after production. This allows FPGAs to be optimised to perform a specific function extremely efficiently with comparatively low latency. The result is a much greater power efficiency for the same performance when compared to standard processors.

I believe that the integration of this piece of hardware into autonomous navigation systems will allow its users to experience ultra-high speed object detection with a fraction of the power demands of more commonly used processors. If this is true, FPGAs can be implemented into a range of robotic systems, from self-driving cars to healthcare robots, to greatly reduce their power consumption, making them more lightweight and sustainable without sacrificing performance.

Methodology and Outcomes

My project would consist of using deep learning to train a convolutional neural network (CNN) which can be deployed using an FPGA to detect and track cones from a camera input. I chose to use cones as the sample object as they are often used as obstacles in the development of autonomous driving systems. This means there is a good amount of resources available online to aid in the development of the system, such as reliable training data and pre-trained models. The development of the CNN would involve using deep learning libraries such as Pytorch or



TensorFlow to create and train the neural network. Reliable open source training data could be used or alternatively data could be created with the use of a camera and manually labelling the data myself. The data would have to be reconfigured and processed before use.

Possible obstacles in the development include debugging the model and potential training time delays. To combat this, I intend on making use of the many pre-trained cone detection models available online in order to speed up development time. Training time can also be reduced through sourcing more processing power and smarter, more appropriate, training algorithms.

Running parallel to this, I will also be writing Verilog code, a hardware description language, to design the hardware and system architecture of the FPGA. This involves configuring and optimizing logic blocks on the chip. Logic blocks are collections of fundamental logic gates, optimising the design of these logic blocks will increase the efficiency of the system. This section of the project can be done during the training time of the neural network, and thus can be worked on alongside the last section.

In order to implement the system onto the hardware, tools such as Xilinx's Vitis-AI can be used to convert PyTorch and Tensorflow deep learning models into modules which can be used by the FPGA. Vitis-AI also offers optimization tools which can be used to reduce the complexity of the CNN, again improving the latency of the system. The use of these off-the-shelf tools will again speed up development time.

Once the system has been successfully exported onto the processor, I can begin to evaluate its performance and iterate on the design. The FPGA and necessary electronics will be mounted on a test vehicle, for example a manually controlled buggy, and the efficacy of the system can be measured. The performance of the system will be measured using a few different metrics such as the neural networks detection accuracy, false positive/negative rates, power consumption, operational speed, etc. These values can then be compared against more commonly processors in the same environment.

At the end of the project, an analysis of the performance will be conducted to highlight the positives and potential drawbacks of the system. The design of both the hardware and the neural network will be critiqued and possible improvements will be suggested.

The Gantt chart below shows an estimate of the time needed for each section of the project :



Tasks	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Aquiring and Processing Training Data	Dark Blue					
CNN Development		Dark Blue				
Verilog Module Creation		Dark Blue				
Implementation onto FPGA			Blue			
Testing and Evaluation					Light Blue	
Report Writing						Purple

Costs

The only costs of the project is the FPGA board itself as well as the mounted cameras. The cameras will not need to be bought first-hand, most compatible preowned cameras available in Trinity should be adequate. My supervisor suggested the use of the Xilinx’s Kria Systems-on Module (SoM) FPGA for the project. This board would be perfect for the project due to its included ARM processor as well as its ecosystem of accelerated applications and prebuilt modules for computer vision. This piece of hardware will likely have to be purchased, a full Kria KV260 Starter Kit has a estimated cost of \$200.

Interdisciplinary Focus and Collaboration

My research project will touch on both the fields of computer science and electronic engineering, combining deep learning and AI with the hardware focused side of robotics engineering. I plan on both working closely with my reasearch supervisor from the Department of Electronic and Electrical Engineering as well as some mentors from Formula Trinity Autonomous, the autonomous racing branch of the student-led motorsports team in Trinity. Formula Trinity Autonomous have a talented perception team and, due to their experience with high-speed autonomous racing, I believe their input throughout the project will be invaluable.

Research Supervisors

For my research supervisor, I selected Dr Shreejith Shanker from the Department of Electronic and



Electrical Engineering. I believe Dr.Shanker would be a great research supervisor due to his research with reconfigurable digital systems and autonomous embedded systems. Moreover, Dr Shanker also has experience using FPGAs in automotive systems. This in particular will help me with the implementation phases of the projects, allowing me to explore more of the theory and design a better system.