Project Proposal

Multirotor Computing Platform with FPGA Hardware Acceleration for Machine Learning

CPEN/ELEC 491 Capstone Team 109

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Revision History

The full revision history and commited changes of the document can be found in the git repository history: https://github.com/Capstone-Skynet/Capstone-Skynet.github.io/commits/master.

Version #	Initials	Release Date	Changeset	Changes Made
0.0	MH	2019-09-30	4de1f50	Initial skeleton of the document.
1.0	MW	2019-10-08	023dd34	First draft.
1.1	MH	2019-10-09	fe02e2c	Revised section 4.
1.2	PD	2019-10-12	660e001	Revised sections 1, 2, and 4.
1.3	MH	2019-10-13	b3fda54	Revised sections 3 and 4; updated title.
1.4	PD	2019-10-14	29ba572	Comprehensive revisions, final draft.
1.4.1	MH	2019-10-14	7c7c331	Updated title page.

Contents

Terms and Abbreviations

Technical terms and abbreviations dictionary go here.

Term	Definition
NN	
CNN	
RNN	
YOLO	
TX	Transmitter.
RX	Receiver.
TC	Transport Canada.

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1 About This Document

1.1 Purpose

This document serves to facilitate a high-level understanding between the client and the student team regarding the goals and responsibilities of each party throughout the proposed Capstone project. In addition to providing an overview of the project's background, objectives, and requirements, this document details how the project will be managed, provides a tentative project timeline, and documents the student team's risk mitigation strategies.

1.2 Intended Audiences

The client, Professor Mieszko Lis, is the primary consumer of this document. The proposal is intended to present the client with a high-level overview of the project's implementation, both technical and administrative, as envisioned by the student team — providing the client an opportunity to offer corrective feedback if required.

Secondary consumers of this document include the Capstone program's instructional team (serving as an update to the project's progress through Milestone I) and the authoring Capstone team itself (acting as a reference for for design decisions and project planning throughout the duration of the project).

2 Background

2.1 Business Background

The client of this project is Professor Mieszko Lis, a professor in the Electrical and Computer Engineering department at the University of British Columbia (UBC). A particular research focus of Dr. Lis is the acceleration of (traditionally software-based) machine-learning (ML) models through the use of dedicated hardware.

The fabrication of custom-designed hardware is often prohibitively expensive — the manufacture of application-specific integrated controllers (ASICs) can easily cost millions of dollars and take several years to complete. This is inherently unconducive to the quick, iterative prototyping required by small-scale research operations like those run by Dr. Lis. To mitigate this constraint, Dr. Lis would like to use Field Programmable Gate Arrays (FPGAs) to prototype his ML hardware designs. FPGAs are effectively programmable analogs of ASICs – trading off maximal circuit complexity and performance with a near-instant implementation time (a design can be implemented on an FPGA in a manner of minutes to hours) — facilitating the rapid turnaround time required by Dr. Lis. Once a finalized design has emerged from the prototyping process performed on the FPGA, the design can then be converted and implemented on an actual integrated controller, if desired.

2.2 Project Context

In late 2020, Dr. Lis will undertake a research project assessing the feasibility of converting software-based machine-learning models into efficient hardware designs through the use of High-Level Synthesis (HLS) tools. Dr. Lis would like to obtain a drone-mounted, FPGA-based demonstration platform in order to demonstrate the mobility and applications of his research.

In addition to the construction of demonstration platform, Dr. Lis would like an initial machine-learning application implemented on the device. This initial application will use a drone-mounted video camera to identify pedestrians through the use of machine learning, wirelessly transmitting the video and extracted pedestrian information to an external device ("base station"). Dr. Lis will use this developed application as a starting point for further modifications/improvements stemming from his research. Additionally, the application could be used for a wide variety of purposes as-is, including applications towards disaster response, wildlife management, and demographic studies.

The student team selected to undertake this project is comprised of five students in the Capstone program offered by the Department of Electrical and Computer Engineering at the University of British Columbia.

3 Objectives, Goals, and Constraints

This section elaborates the objectives to be pursued in the project, the goals to be achieved, and constraints which might limit the project's scope and success.

The precise usage of the terms used throughout this section are as follows:

- **Objectives**: The high-level requirements of the project, all of which are required for the project to be deemed a success.
- **Goals**: The planned project specifications which will ultimately implement the project's objectives.
- **Constraints**: Factors which might alter or limit the execution of the project's goals and objectives.

3.1 Objectives

The main objectives are sorted by the client's priority in descending order.

Integration of FPGA/Computer Vision Hardware with a Drone: As the ultimate deliverable consists of a highly mobile computing platform, our utmost objective is the successful integration of computation hardware with the drone. The equipment for capturing video data, performing processing, and transmitting digital data must be reasonably compact and easily deployable.

Air-to-Ground Data Transmission: Critical to research and analytics, the drone payload must be able to transmit video sensor data, in addition to processed data from the onboard hardware accelerator (FPGA). There must be a ground station, consisting of a receiver and a display device (such as a mobile phone or computer) which receives and decodes the transmission for display, providing the user with a real-time video stream overlaid with machine learning intents.

Machine Learning Implementation on the FPGA: The hardware-accelerated computing platform must correctly interface with attached peripherals (such as the camera sensor, the data transmitter (DTX), and other necessary hardware) through the use of well-defined communication protocols, such as serial or PCI-E (whichever is suitable given bandwidth requirements). The hardware accelerator must feature a starter ML model, implementing existing ML structures/frameworks such as (but not limited to) CNNs, RNNs, or YOLO,[1] being fully capable of basic computer vision tasks.

3.2 Goals

The ultimate goal of this project is to develop a mobile computing platform which utilizes an FPGA to perform hardware-accelerated machine learning tasks and deploy it on an unmanned multirotor aerial system (drone).

The drone should be piloted manually within the line-of-sight (LOS) of the pilot, using a ground-to-air transmitter (TX) in the form of an off-the-shelf radio controller and receiver combination. The drone should feature a flight controller capable of self-stabilization using well-tuned PIDs and, with the payload attached, the drone's flight duration should be at least 50% of that without the payload (typically 10–15 minutes). The total takeoff mass of the integrated system should not exceed 25 kilograms — as specified by Transport Canada, as a pilot with a *Basic* or *Advanced Operations* certificate cannot operate a drone heavier than 25kg.

The machine learning model should analyze the video stream from the onboard camera and detect pedestrians within the frame with near-humanlike accuracy. The model should exploit the FPGA's inherent parallelism to accelerate key ML tasks such as matrix multiplication and convolution. The model should output screen-space location of the detected pedestrians, with this prediction having a tolerable update latency of one second or less. In addition, the base station should display *bounding boxes* surrounding the model's pedestrians predictions, overlaying a video of reasonable quality (at least 640x480, 10fps).

3.3 Constraints

The most pressing constraints are of an administrative nature. The project described herein is very large in scope — the constrained 8-month development period will likely affect the team's maneuverability and ability to comprehensively mitigate risks. In addition, navigating regulatory hurdles regarding drone piloting and radio data transmission (set out by Transport Canada and Industry Canada, respectively) will incur additional time and resource constraints.

As this device is intended to be used as a development platform in the future, it is important that it is future-proofed for further modifications. As detailed in Section 2.1, FPGAs are inherently constrained with regards to on-chip resources. An appropriately-sized FPGA will need to be selected, capable of implementing the base-level "glue-logic" required for the platform to operate (for example, the camera interface and data transmission logic), while still leaving enough available resources on the FPGA for Dr. Lis to implement his own ML models after the project's delivery. This constraint is tightly coupled with the high level of legacy risk inherent in this project, as outlined in Section 4.6.

The physical properties of the payload (FPGA, electronics, camera, and DTX) is an additional constraint. Since the purpose of the project is to validate the viability of mobile ML designs, the payload should be light, compact, and power efficient, such that it can be carried on a drone for a reasonable flight time in order to carry out useful ML applications. The weight of the payload (and its required batteries) affects total flight duration, maximum altitude, airspeed, and maneuverability.

As the bandwidth of video transmission is limited by transmission frequency and the transmitter (DTX) itself, critical communication-related design decisions must be made early in the project. A transmitter with slightly longer range would significantly increase the power consumption due to inverse-square law.[2] Moreover, the data throughput depends heavily on a successful implementation of the communication protocols the student team decides to choose. Clever compression or encoding techniques might need to be employed to enhance the throughput and achieve a reasonable result.

4 Project Plan

4.1 Final Milestone & Ultimate Deliverables

This project concludes on **April 3rd, 2020**, at which point the client and the instructors will receive the following project deliverables:

4.1.1 Hardware Artifacts

1. **Drone Prototype**: A fully integrated FPGA computing platform mounted on a remote-controlled drone that can capture video using an on-board camera. The computing platform utilizes FPGA-based neural network accelerators to process the video data and detect and track one or more designated objects. The platform transmits video data and associated machine learning metadata to a ground station.

2. **Ground Station Prototype**: A system that receives wireless video data and machine learning metadata from the drone and displays both on-screen. The ground station also logs the received data to files for further research and analysis purposes.

4.1.2 Document Artifacts

1. **Requirements Specification**: A document outlining the functional and non-functional requirements of the prototypes.

2. **Design Specification**: A document describing the high-level architecture and design of technical subsystems.

3. **Validation Specification and Results**: A document describing system testbenches, validation techniques, and validation/testing results.

4. **Operations, Maintenance, and Upgrades Specifications**: A document, similar to a operation manual, outlining installation instructions, recommended maintenance, and common troubleshooting guides.

5. **List of Deliverables**

4.1.3 Other Artifacts

1. **Demonstrative Video**

2. **Oral Presentation and Poster**

3. **Project Repositories**: Repositories that include all source code, generated netlists, CAD designs, spreadsheets, and other documents.

4.2 Intermediate Milestones

There are three project milestones to track project progress. Milestones necessitate the delivery of in-progress documents listed in Section 4.1.2. Each milestone contains an oral presentation which summarizes the project progress up to the milestone.

4.2.1 Milestone I

Milestone I (**October 15th, 2019**) necessitates the delivery of the the *Project Proposal* (*this document*), outlining the baseline agreement among all stakeholders with regards the project's administration and scope.

4.2.2 Milestone II

Milestone II (**November 25th, 2019**) is the first prototype review. The review features initial progress in camera interface and machine learning accelerator implementations on the FPGA. If the project progress is on track or ahead, we will demonstrate a video-capture implementation synergizing with an onboard ML model. Otherwise, we will demonstrate these components functioning independently.

4.2.3 Milestone III

Milestone III (**February 10th, 2020**) is the second prototype review. The review features improved ML accelerator and drone implementations. We will focus on effort invested into video transmission and power supply circuitry.

4.3 Major Responsibilities

4.3.1 Team Responsibilities

The student team is responsible for the day-to-day development, management, and operations of the project. The team is responsible for the final delivery of all artifacts listed in Section 4.1. The team is expected to conduct research from academic or industry sources for implementation methods, techniques, or processes. The team is additionally responsible for managing the project's finanaces/inventory, and acquisition of key materials, electronics, and hardware.

4.3.2 Client Responsibilities

The client is responsible for being available to meet in-person or online given reasonable notice. They are expected to provide necessary subject education or training materials upon request. They are also expected to provide additional financial support if needed (see Section 4.5 for more details).

4.4 Schedule

4.4.1 Major Schedule

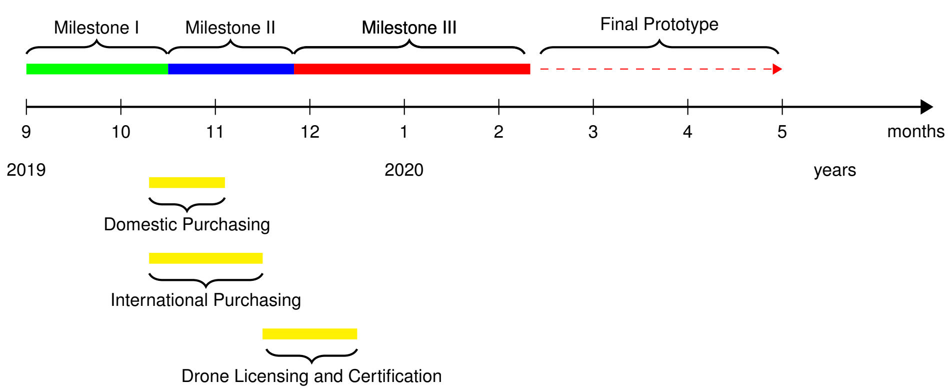

Figure 1: Project Timeline

The tentative timeline of the project is detailed in Figure 1. Specific deliverables and goals for each milestone are detailed in Sections 4.1 and 4.2.

4.4.2 Weekly Schedule

All team members have agreed to reserve the following time slots for group/client meetings, presentation preparations, and general developmental work:

- Tuesday, 15:00 - 17:30
- Thursday, 15:00 - 17:30
- Friday, 8:00 - 10:00

The team members also acknowledge that significant amounts of development effort will fall outside of these designated periods.

Team meetings are scheduled for Tuesdays at 15:30 in the Macleod Building, and meetings with the instructional team are currently scheduled for Thursdays at 16:00 in the Irving K. Barber Learning Centre. Meetings with the instructional team will transition to 15:30 on Tuesdays beginning in Term 2.

Formal client meetings will be held on an irregular (roughly weekly) basis, dependent on the client's availability. Peter Deutsch, the principal point of contact for the client, will provide additional project updates as needed via email, Skype, or informal in-person discussions.

4.5 Budget

The budget of this project is flexible, with an estimated upper limit of C$1000. The Capstone program provides C$650 towards this budget. The client has agreed to contribute an additional C$300 to C$500 if necessary, on the condition that they have been provided with justification and have given their explicit approval.

Table 1: Expected Project Expenses

Item	Estimated Price	Remark
Camera	$ 30.00	Camera Module
Transceiver	$ 40.00	
Drone	$ 400.00±200.00	Significantly less costly if departments of ICICS or UBC Unmanned Aerial Systems (UAS) lends a drone to the student team to modify.
Drone RX and TX	$ 150.00±100.00	Drone controller and receiver is necessary if the above drone package does not have them included.
FPGA	$ 300.00±100.00	
Battery Pack	$ 40.00	
Accessories	$ 50.00	

4.6 Risk Profile

4.6.1 Risk Management

The student team has generated a list of potential risks which threaten the viability of the project and have assigned a likelihood and impact value to each of them (Table 2). The *risk index* for each risk is the product of these two values: *likelihood* and *impact*.

To mitigate the outlined risks, the following risk management protocol is followed:

If the risk index is **greater or equal to 0.4**, then the risk mitigation protocol *must* be followed. This entails creating a card for the specific risk on Trello (the team's project management tool), discussing the status of the risk during the weekly group meeting, and providing immediate updates to the status of the risk on Slack as they occur.

If the risk index is **less than 0.4**, then the above risk mitigation protocol *may* be followed, if deemed necessary. Otherwise, the risk is simply monitored for updates.

The risk profile is updated/reviewed weekly (during the team meeting) and as otherwise necessary.

4.6.2 Potential Risks

Table 2: A risk profile table outlining the a list of potential risks.

Risk description	**Likelihood**	**Impact**	**Risk (↓)**
Drone flight hardware (flight controllers, radio, motors) cannot function to crashes and damages.	0.9	1.0	0.90
Payload is too heavy which significantly increases drone motor requirements and significant reduction in flight duration.	0.8	0.8	0.64
Accidents that damage the drone and computating equipment that require extra budget that we may not have.	0.6	0.9	0.54
Loss of drone hardware and payload during flight and cannot be recovered (total loss).	0.5	1.0	0.50
Not enough time commitment from team members.	0.7	0.7	0.49
Access to tools and shops for modifiying and repairing drone hardware is inadequate or non-existent.	0.6	0.8	0.48
Underestimation of project scope or work required, leading to insufficient time managemnet and burn-outs.	0.5	0.9	0.45
Payload is too heavy which exceeds total take-off weight.	0.4	1.0	0.40
Legacy documents for the project is insufficient, resulting in the final product unable to be maintained or extended.	0.7	0.5	0.35
Financial inefficiencies leading to overbudget or lack of capital.	0.4	0.8	0.32
Constrained to purchase lower-quality components due to budget and results in lower performance.	0.6	0.5	0.30
Team is indecisive or team leader cannot make a timely decision — results in delay.	0.4	0.6	0.30
Development and managment technique and methodology is not effective, leading to productivity losses.	0.4	0.7	0.28
Not enough time to work on documentation.	0.7	0.4	0.28
Scope of the project is overestimated which leads to diversification of vision of the project.	0.5	0.5	0.25
Not enough machine learning training data.	0.5	0.5	0.25
Not enough FPGA logic elements to implement a desired ML model.	0.5	0.5	0.25
Failure to acquire regulatory compliance resulting in inability fly drone legally.	0.3	0.7	0.21
The software, tools or development environment for the project is inadequate.	0.4	0.5	0.20
Knowledge and skill regarding ML is insufficient.	0.5	0.4	0.20
Technical debt paydown impact project timeline.	0.4	0.5	0.20
Deliverables and objectives failing to meeting client's expectations.	0.2	0.9	0.18
Client demands modification to the scope and requirements of the project that leads to delays or feature cuts.	0.3	0.6	0.18
Team lacking in effective communication which leads to overlapping work, missed work, and incompatible work.	0.4	0.4	0.16

Continued on next page

Table 2 – *Continued from previous page*

Risk description	**Likelihood**	**Impact**	**Risk (↓)**
Internal documentation or documentation for libraries and parts are not sufficient for development.	0.4	0.4	0.16
Camera module lacking in documentation.	0.2	0.8	0.16
New technology or research that changes the scope significantly.	0.2	0.5	0.10
Sabotage of the project.	0.1	1	0.10
Sudden loss of client.	$\leq$0.1	1	0.10
Sudden loss of team member.	$\leq$0.1	0.9	0.09
FPGA board lacks documentation.	$\leq$0.1	0.8	0.08
Client is not cooperative or does not provide necessary information.	$\leq$0.1	0.8	0.08
Key components are not available or takes too long to deliver.	0.1	0.7	0.07
Purchased orders of equipment or tools delayed or lost.	0.1	0.5	0.05
Client is not available enough to provide significant help.	$\leq$0.1	0.5	0.05
Lacking resources in machine learning knowledge.	$\leq$0.1	0.5	0.05
Camera module fail to interface with FPGA.	$\leq$0.1	0.5	0.05
Data transmitter fail to interface with FPGA.	$\leq$0.1	0.5	0.05
Competitions on the market significantly affecting project requirement and scope.	$\leq$0.1	0.4	0.04
Software license does not allow our application to be delivered.	0.1	0.3	0.03
Laws regarding drone operation and piloting change significantly.	0.1	0.2	0.02

5 Approval

The client and Capstone team have reviewed the content of the proposal, accept the outlined scope of the project, and agree to the responsibilities outlined therein.

Client

Mieszko Lis — Date

Capstone Team

Peter Deutsch — Date

Muchen He — Date

Arthur Hsueh — Date

Meng Wang — Date

Ardell Wilson — Date

References

[1] J. Redmon, S. Divvala, R. Girshick, and A. Farhadi, “You only look once: Unified, real-time object detection,” 2015.

[2] “Inverse Square Law.” https://en.wikipedia.org/wiki/Inverse-square_law, 2019. Online; accessed October 13, 2019.