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 this document can be found in the git repository:
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.
1.5	MH	2019-10-14	-	Updated risk profile.
1.6	MH	2019-10-14	-	Minor edits, fixed pronouns, and update to project context; added terms and abbreviations page.
1.7	PD	2019-10-14	-	Final revision and release.

Contents

Terms and Abbreviations

Term	Definition
ANN	Artificial Neural Network, or simply “Neural Network”, is a data processing model modeled after neuron interactions. The process consists of forward propagation through the use of several matrix multiplications.[1]
ASIC	Application-Specific Integrated Circuit.
CNN	Convolutional Neural Networks are neural networks which are especially useful for image classification.[2]
ECE	Department of Electrical and Computer Engineering at the University of British Columbia.
FPGA	Field-Programmable-Gate-Array, a “programmable” hardware unit that allows for ASIC-like performance with software-like turn-around time and flexibility.
FPS	Frames Per Second.
GPU	Graphics Processing Unit, a discrete piece of hardware designed to accelerate graphics-intensive or other parallel computing tasks.
ICICS	Institute for Computing, Information, and Cognitive Systems at the University of British Columbia.
LOS	Line-of-sight.
ML	Machine Learning.
Multirotor	An unmanned vehicle with multiple engines.
OTS	Off-the-shelf, or commercially available/purchasable.
PID / PID Controller	Proportion-Integral-Derivative controllers denote the most common control algorithm for precise and accurate movement in multirotor applications.[3]
RNN	Recurrent Neural Networks are neural networks where the output depends on previous computations, effectively consisting of memory.[4]
RX	Receiver.
TC	Transport Canada.
TX	Transmitter.
YOLO	You-Only-Look-Once is a fast ML algorithm which detect objects, but is unlike CNN or RNN.[5,6]

List of Figures

List of Tables

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 of the project is the primary audience 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.

The secondary audience of this document is the Capstone program's instructional team, who analyze and assess the project through the lens of common stakeholder positions (including users, designers, legal personnel, and quality controllers).

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). One of the client's particular research foci 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 circuits (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 the client. To mitigate this constraint, the client would like to use Field Programmable Gate Arrays (FPGAs) to prototype their 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 the client. Once a finalized design has emerged from the prototyping process performed on the FPGA, the client may convert and implement the design on an actual integrated controller, if desired.

2.2 Project Context

In late 2020, the client 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. The client would like to obtain a drone-mounted, FPGA-based demonstration platform in order to demonstrate the mobility and applications of their research.

Although the idea of utilizing FPGAs on drones has been explored commercially,[7] existing products focus on utilizing the FPGA for *flight control* rather than implementing general purpose tasks (such as ML). To the best of the team's and client's knowledge, no general purpose drone-based FPGA platforms exist, nor can any existing commercial devices be retrofitted to implement ML tasks due to their restricted design scope.

In addition to the construction of the demonstration platform, the client 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"). The client will use this developed application as a starting point for further modifications/improvements stemming from their 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, the student team's utmost objective is the successful integration of computation hardware with a 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. The hardware accelerator must feature a starter ML model, implementing existing ML structures/frameworks such as (but not limited to) CNNs, RNNs, or YOLO,[5] ultimately being 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.[8]

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 the 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 pedestrian 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[8] and radio data transmission[9] (set out by Transport Canada and Industry Canada, respectively) will incur additional time and resource constraints. Particular focus will need to be placed on the fact that UBC is within controlled airspace[10] which prohibits the use of drones without special permits — potentially limiting the team's ability to test the drone on-site.

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 the client to implement their 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 (10–15 minutes) 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. Moreover, the data throughput depends heavily on a successful implementation of the communication protocols the student team decides upon. 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 machine learning accelerators to process the video data and detect and track one or more pedestrians. 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, the team will demonstrate a video-capture implementation synergizing with an onboard ML model. Otherwise, the team 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. The team 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 additionally responsible for managing the project's finances/inventory, including the acquisition of key materials, electronics, and hardware.

The team is tentatively divided into a *drone team* (consisting of Muchen, Arthur, and Ardell) and an *FPGA team* (consisting of Peter and Wilson). This division of labour is only an initial approximation, and will likely change over time.

4.3.2 Client Responsibilities

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

4.4 Schedule

4.4.1 Major Schedule

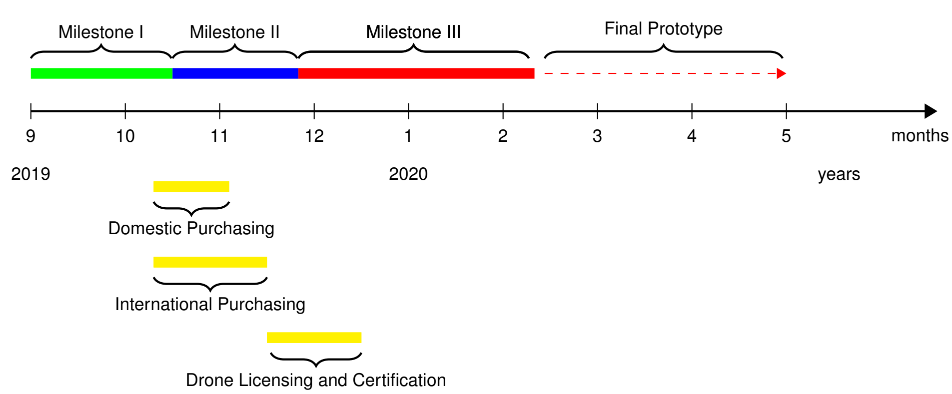

Figure 1: Project Timeline

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, and 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: Potential Project Expenses

Item	**Estimated Price**	**Remark**
Camera	$ 30.00	
Transceiver	$ 40.00	
Drone	$ 400.00±200.00	Significantly less costly if ICICS or the UBC Unmanned Aerial Systems team 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	There exists FPGA development boards that could be provided by the ECE department, which eliminates this cost.
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 strategy 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 by any team member. 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: Risk Profile

Risk description	**Likelihood**	**Impact**	**Risk (↓)**
Drone flight hardware (flight controllers, radio, motors) cannot function due to crashes and/or damage.	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 computation equipment that require extra budget that we may not have.	0.6	0.9	0.54
Total loss of drone hardware and payload during flight.	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 modifying 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 management 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 are insufficient, resulting in poor maintainability/extensibility for the client.	0.7	0.5	0.35
Financial inefficiencies leading to budget overruns or lack of capital.	0.4	0.8	0.32
Constrained to purchase lower-quality components due to budget, resulting in lower performance.	0.6	0.5	0.30
Team is indecisive or cannot make a timely decision — resulting in delay.	0.4	0.6	0.30
Development and management technique/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
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 impacts project timeline.	0.4	0.5	0.20
Deliverables fail to meet 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

Continued on next page

Table 2 – *Continued from previous page*

Risk description	**Likelihood**	**Impact**	**Risk (↓)**
Team lacks ineffective communication skills which lead to overlapping work, missed work, and/or incompatible work.	0.4	0.4	0.16
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 emerges, changing 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.	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
Lack of resources to acquire machine learning knowledge.	$\leq$0.1	0.5	0.05
Camera module fails to interface with FPGA.	$\leq$0.1	0.5	0.05
Data transmitter fails to interface with FPGA.	$\leq$0.1	0.5	0.05
Market competition significantly affects project requirements 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 Signature

Mieszko Lis	Date (YYYY-MM-DD)

Capstone Team Signatures

Peter Deutsch	Date (YYYY-MM-DD)
Muchen He	Date (YYYY-MM-DD)
Arthur Hsueh	Date (YYYY-MM-DD)
Meng Wang	Date (YYYY-MM-DD)
Ardell Wilson	Date (YYYY-MM-DD)

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