Project Proposal

Multirotor Computing Platform with FPGA Hardware Acceleration for Machine Learning

CPEN/ELEC 491 Capstone Team 109
University of British Columbia

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Revision History

Revision history written here.

Version #	Initials	Release Date	Changes Made
0.0	MH	2019-09-30	Initial skeleton of the document.
1.0	MW	2019-10-08	First draft.
1.0.1	MH	2019-10-09	Revised section 4.
1.0.2	PD	2019-10-09	Revised sections 1, 2, and 4.
1.0.3	MH	2019-10-13	Revised sections 3 and 4; updated title.

Contents

Terms and Abbreviations

Technical terms and abbreviations dictionary go here.

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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 with an opportunity to provide corrective feedback as desired.

Secondary consumers of this document include the Capstone program's instructional team (serving as an update to the project's progress through Milestone #1) 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 and iterative prototyping required by small-scale research projects 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 assembled by the Department of Electrical and Computer Engineering at the University of British Columbia.

3 Objectives, Constraints, and Goals

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

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

- **Objectives**: Also referred sometimes as *requirements*. These are a list of *yes-or-no* qualities that the student team would like to achieve in order to consider the project as "successful".
- **Constraints**: The constraints are limiting factors that affect the variability of our success, and to what extent our goals can be achieved.
- **Goals**: Goals are quantitative specifications that would be ideal to achieve; they are the target specification the student team is aiming for, but are not strictly necessary for the project to be deemed successful.

3.1 Objectives

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

Integration of Electronics with the Drone: Since the ultimate deliverable consists of a highly mobile computing platform, our utmost objective is a successful integration of computation and processing hardware with the drone. The equipment for capturing video data, performing processing, and transmitting digital data should be reasonably compact and easily deployable. The thermal characteristics and total power consumption of the device should be reasonable such that they affect minimally on the flight characteristics of the drone.

Air-to-Ground Data Transmission: Critical to research and analytics, we need to ensure the drone payload is able to transmit video sensor data, as well as the processed data from the onboard hardware accelerator (FPGA). There is a ground station, consisting of a receiver and a display device (such as a mobile phone or computer) receives and decodes the transmission for display, providing the user with a real-time video stream overlaid with machine learning intents. The wireless frequency and band chosen is compliant with local laws; no further actions are required if we utilize the WiFi protocol (802.11n/ac in 2.4GHz or 5.2GHz) using off-the-shelf WiFi modules.

Machine Learning Implementation on the FPGA: The hardware-accelerated computing platform correctly interfaces with attached peripherals such as the camera sensor, the data transmitter (DTX), and other necessary hardware through use of well-defined communication protocols, such as serial or PCI-E (whichever is suitable given bandwidth requirements). The FPGA should feature a starter ML model, such as (but not limited to) CNN, RNN, or YOLO, fully capable of basic computer vision. The netlist design for the ML models are adequately synthesized, resulting in an efficient datapath.

3.2 Constraints

In pursuit of the objectives listed above, the main constraints relating each main objective is as follows:

The most important constraints are the non-technical ones. The project described here is considered very large in scope. The limited 8-months period is extremely limiting and thus will affect design decisions. The budget is a significant constraint which will affect the components and parts the student team chooses.

The physical properties of the payload (FPGA, electronics, camera, and DTX) is an important constraint. Since the purpose of the project is to validate the viability of mobile ML designs, the payload should be light and compact such that it can be carried on a drone for a reasonable flight time in order to carry out ML applications. The weight of the payload affects total flight duration, maximum altitude, airspeed, and maneuverability. There is a maximum cutoff for weight such that adding more battery capacity would actually negatively affect flight duration.

The power consumption of the onboard electronics also affects drone performance. The computation tasks done on the FPGA are relatively intense, drawing significant energy from the drone's battery. The power emission is also a constraint, excess heat from the processing hardware need to be dissipated; however this constraint is not expected to be overly limiting.

The bandwidth of video transmission is limited by transmission frequency, transmitter (DTX), and the implementation to interface with the transmitter. A transmitter with slightly longer range would significantly increase the power consumption due to inverse-square law.[1] Moreover, the data throughput depends heavily on a successful implementation of the communciation protocols the student team decides to choose. Clever compression or encoding techniques may be employed to enhance the throughput and achieve a reasonable result.

The FPGA is a highly adaptive device that can deliver almost-ASIC level speed but a large number of logic elements are required to implement a large model such as a machine learning - computer vision - model. The inherit constraints with FPGA RTL designs such as timing, area, and power constraints will ultimately limit the processing throughput of the video data. Bottleneck for limiting processing resolution and frequency (frame rate).

Common machine learning models for computer vision is designed for GPU to maximize parallel computing. The FPGA cannot match GPU data throughput, thus the limited amount of logic elements would also constrain our architecture design.

3.3 Goals

The main goal by is to have a fully functioning integrated system of a computing platform with hardware accelerated machine learning using an FPGA device. The computing platform is highly-mobile and easily deployable with the use of an unmanned multirotor aerial system (drone).

The drone is piloted manually within the line-of-sight (LOS) of the pilot, using a ground-to-air transmistor (TX) either using an off-the-shelf radio controller and receiver combination, or WiFi. The drone features a flight controller capable of self-stabilization using well-tuned PIDs. With the payload attached, the drone's flight duration should be at least 50% that of 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, a pilot with *Basic Operations* certificate or *Advanced Operations* certificate cannot operate a drone heavier than 25kg.

On-board the drone, the camera sensor should stream video data to the processing hardware (including the FPGA). The FPGA act as a hardware accelerator to speedup ML related or parallel tasks such as matrix multiplication and convolution. The hardware should sustain a reasonable quality of video at 640x480 (VGA) resolution at a rate of at least 10 frames per second (fps). Both the video and the process ouput data are to be transmitted to a ground station, also sustaining the same sample rate and resolution.

The ground station is capable of receving the data transmitted by the hardware on the drone. The ground station device should be able to decode and display the video and ML data in real time to the operator.

4 Project Plan

This section outlines a preliminary responsibilities and tasks to be carried out.

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 computing

platform may optionally be equipped with a co-processor. 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 display video and overlayed metadata in the form of *bounding-boxes*. The ground station system also log the received data to files for further research and analysis purposes.

4.1.2 Document Artifacts

1. **Requirement 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 and testing results.
4. **Operations, Maintenance, and Upgrades Specifcations**: 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 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 video- capturing implementation synergizing with 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, power supply circuitry, and batteries.

4.3 Major Responsibilities

This subsection covers the major responsibilities expected from the student team and the client.

4.3.1 Team Responsibilities

The student team is responsible for day-to-day development, management, and operation of the project by coordinating group and client meetings. 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. Finally, the team is responsible for managing project finanace, inventory, and acquisition of key material, electronics, and hardware.

4.3.2 Client Responsibilities

The client is responsible for being available to meet in-person or online given a reasonable notice of one week. They are expected to provide (reference to) necessary education or training material. They are also expected to provide additional financial support if needed (see section 4.5 for more detail).

4.4 Schedule

4.4.1 Major Schedule

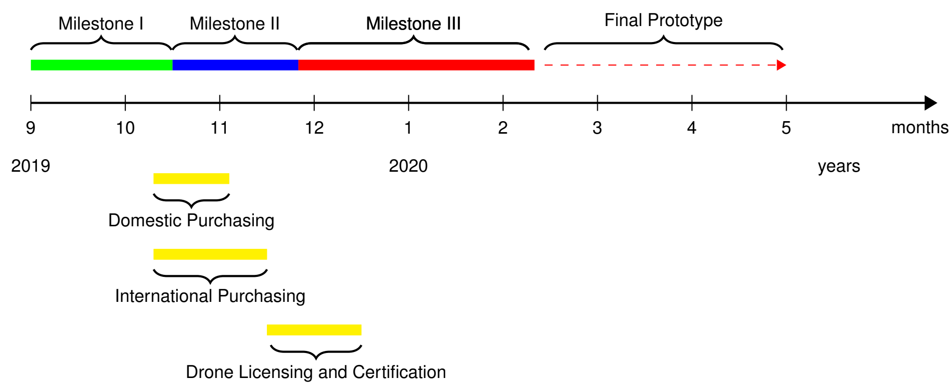

Figure 1: Project Timeline

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: The expected expenses for the required components to be purchased for the project.

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 Capstone 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 value).

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: Risk profile

Risk description	**Likelihood**	**Impact**	**Risk**
Drone cannot take off at all due to drone hardware failure.	0.6	1.0	0.6

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Table 2 – *Continued from previous page*

Risk description	**Likelihood**	**Impact**	**Risk**
FPGA logic capacity is not enough to implement our solution.	0.5	1	0.5
Electronics and battery are too heavy for the drone to take off.	0.5	1	0.5
Accidents that damage to drone and FPGA that leads to extra budget that we may not have.	0.7	0.7	0.49
Forced to buy cheaper components which leads to lower performance.	0.8	0.5	0.4
Deliveries is not meeting client's expectations	0.2	0.8	0.4
Knowledge and skill (Machine Learning and Computer vision) required for project is not sufficient.	0.5	0.8	0.4
Our scrum method is not efficient	0.5	0.7	0.35
Scope of the project is underestimated which leads to burn outs	0.5	0.7	0.35
Not have enough money.	0.5	0.7	0.35
Not enough time commitment from team member due to other courses.	0.5	0.6	0.3
Team is indecisive which leads to delay — management is not good enough to make a timely decision.	0.4	0.7	0.28
Team has lack of communication and make assumptions which leads to incompatibility	0.4	0.7	0.28
Documentation is not specific / complete.	0.7	0.4	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
Illegal to fly drone.	0.3	0.8	0.24
New technology or research that changes the scope significantly	0.3	0.7	0.21
Technical debt paydown impact project timeline.	0.4	0.5	0.2
Software license does not allow our application to be delivered.	0.3	0.6	0.18
Key hardware components not available	0.2	0.8	0.16
Machine learning resources lack documentation	0.3	0.5	0.15
Camera lack documentation	0.3	0.5	0.15
FPGA lack documentation	0.3	0.5	0.15
Delivered documentation not adequate for usage and upgrade.	0.5	0.3	0.15
Selected software methodology creates issues with team member that decreases productivity	0.2	0.7	0.14
Legal changes significantly affect project — drones in particular	0.2	0.7	0.14
The final product cannot be maintained or extended.	0.7	0.2	0.14
Client is not cooperative or does not provide necessary information	0.2	0.7	0.14
Client wants to modify scope and requirements that leads to delays or cut features.	0.2	0.6	0.12
Development environment is inadequate.	0.2	0.6	0.12

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Table 2 – *Continued from previous page*

Risk description	**Likelihood**	**Impact**	**Risk**
Sabotage	0.1	1	0.1
Loss of client	0.1	1	0.1
Loss of team member	0.1	0.9	0.09
Equipment shipment is delayed or lost.	0.1	0.8	0.08
Client is not available enough to provide significant help.	0.1	0.5	0.05
Competitive offerings affect project requirement	0.1	0.5	0.05
Camera doesn’t work with FPGA	0.1	0.5	0.05
FPGA doesn’t work with transmission systems	0.1	0.5	0.05

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