Project Proposal

FPGA-Based Machine Learning on a Drone

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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 “Project Plan” section.

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Terms and Abbreviations

Technical terms and abbreviations dictionary go here.

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1 About This Document

This proposal document serves as an agreement between the client and the student team on the goals and responsibilities of both parties towards the proposed project.

1.1 Purpose

The purpose of this document is to describe the project background, objectives and requirements. It outlines the proposed course of action the student team will undertake for the project, as well as the expected contributions between the client and the team.

1.2 Intended Audience

The client is the intended audience of this proposal. This document allows the client to confirm the requirements of the project and have a clear understanding on the course of action the student team will take for the project.

This document is also intended for the instructors and TAs of the Capstone Program. It will allow them to provide assistance to the student team when necessary.

The student team will use this document as a reference for design decisions and project planning throughout the duration of the project.

This proposal is not intended for any other audience than the ones described above and does not serve as a proposal for any other 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 a single application-specific integrated controller (ASIC) 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) - effectively programmable analogs of a real circuit - to prototype his ML hardware designs. Actual hardware designs can be (rapidly) modeled on an FPGA, which acts exactly like a traditional circuit, allowing for rapid iterative prototyping. Once a finalized design has emerged from the prototyping process, it can then be manufactured into an actual hardware chip, 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 constructing the 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. 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 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, Constraints, & Goals

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

The definition that the student team will use will be 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 is not necessary for the project to be considered 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 uttermost most important objective is a successful integration of computation and processing hardware with the drone. The equipment for capturing vidoe data, perform processing, and trasmitting digital data should be reasonbly compact and easily deployable. the total power draw from the drone as well as power output, in terms of thermal output, 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, consist of a receiver and a display device such as a mobile phone or computer receives and decode the transmission for display, providing the client or user with real-time video stream and machine learning intents. The wireless frequency and band chosen is compliant with local laws; no further actions are required if we utilize 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 interfaces with attached peripherals such as the camera sensor, the data transmitter (DTX), and other hardware properly using well-defined communication protocol, such as serial bus or PCI-E, whichever one that is suitable for the data 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 with 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, the payload should be light and compact such that it can be carried on a drone for a reasonable flight time to carry out applications. The weight of the payload affects total flight duration, maximum altitude, airspeed, and manueverbility. 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's performance. The computation tasks done on the FPGA are relatively intense and is a significant pressure to the drone battery. The power emission is also a constraint, excess heat from the processing hardware need to be dissipated; however this constraint is not too severe.

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 a 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

By milestone I (**October 15th, 2019**), the team finishes and submits the *Project Proposal* (*this document*). The document outlines the [baseline agreement among all stakeholders with regards to what is to be accomplished.]FIXME

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 FPGAs. 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

Milestone I - 1 week

Milestone II - 6 weeks

Milestone III - 12 weeks

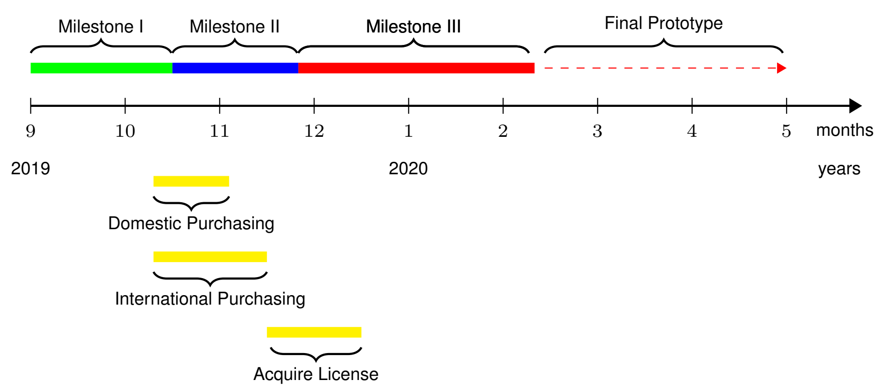

Figure 1: Proposed project plan timeline

4.4.2 Weekly Schedule

The common available time for all team members are dedicated lecture time and lab time for capstone course. These time slots are 3:30PM to 5:30PM on Tuesday and Thursday, and 4PM to 5PM on Wednesday and Friday. The following weekly meetings are scheduled based on this.

Weekly team meeting on Tuesday at 3:30PM.

Weekly meeting with instructor on Thursday at 4:30PM.

Client meeting: by appointment.

4.5 Budget

The department provides a budget of $650.

The following table lists the items required for this project.

Table 1: Required items

Item	Estimated Price	Remark
Camera	$30	Camera Module
Transceiver	$40	
Drone	TBD	
FPGA	TBD	
Battery Pack	$40	
Accessories	$50	

4.6 Risk Profile

4.6.1 Risk Management

Risks can have big influences on the whole project. It is important that we have an effective protocol to handle the potential risks.

The team has generated a list of potential risks[1] and assign the likelihood and impact value to each of them according to the purpose and objective of the project. If the risk number, which is the product of likelihood and impact, of a risk is higher than 0.4, then it has a specific post-risk protocol. All the risks will be monitored and if there exits any signal of a risk, corresponding operations will be performed to prevent it from happening.

When a team member notices any signs of a risk, he will send a message to slack channel and add one card on Trello, the project management tool that the team is using, to alert the whole team. The card on Trello board will have a label showing the significance of the risk and the whole team will discuss about the operations that need to be performed.

The risk profile will be updated whenever the situation is changed, i.e. new potential risks emerged.

4.6.2 Risk Table

Table 2: Risk profile

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
Drone cannot take off at all due to drone hardware failure.	0.5	1	0.5

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[1] see section 4.7.2

Table 2 – *Continued from previous page*

Risk description	**Likelihood**	**Impact**	**Risk**
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
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

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Table 2 – *Continued from previous page*

Risk description	**Likelihood**	**Impact**	**Risk**
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

5.1 Acceptance Statement

The client and the capstone team have agreed on the proposal.

5.2 Client Identification

Mieszko Lis	Date

5.3 Capstone Team Identification

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.