McMaster University

Draft System Requirements

4G06 Capstone Design Project

OSTRICH
A Large Scale 3D Scanner

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Revisions

Revision	Date	Authors	Description of Revision
0	Nov 2, 2015	Paul Correia Nicolas Lelievre Bennett Mackenzie Tigran Martikian Balraj Shah Mykola Somov	Initial revision of the SRS.
1	Dec 1, 2015	Paul Correia Nicolas Lelievre Bennett Mackenzie Tigran Martikian Balraj Shah Mykola Somov	Revision of the initial SRS.
2	Dec 2, 2015	Paul Correia Nicolas Lelievre Bennett Mackenzie Tigran Martikian Balraj Shah Mykola Somov	Updated monitored and controlled variables. Abstracted technical details in document. Added "Items Likely To Change". Fixed algorithm diagram such that it completes. Added context diagram. Added rationale as part of functional requirements. Added tolerances for controlled and monitored vars.

1 Introduction

1.1 System Purpose

The advent of three dimensional modeling has revealed many new possibilities in computer graphics used in a multitude of fields ranging from game design to medical applications. As of late, three dimensional scanners have become significantly more accessible to the average consumer and therefore have gained immense popularity among professionals and hobbyists alike.

The main focus of scanning three dimensional objects has however remained transfixed on a relatively small scale, often within a human's reach. Although some hand held three dimensional scanners offer high resolution scans and very detailed renderings, they are limited to house-hold object sizes meaning that larger objects are not easily scanned using such methods.

The goal of this project is to make large-scale three dimensional scanners more readily available to users in need of scanning objects larger than the average hand held scanner can accommodate as well as removing the human element required in scanning to ensure continuously accurate and autonomous scans.

The purpose of this document is to specify the requirements necessary for this project in terms of a general system description as well as the system's capabilities, conditions and constraints. The document will be in continuous revision during the developmental cycle of the project and will aid in keeping requirements in a constant and clear focus.

1.2 System Scope

The OSTRICH (*Object Scanning Tetra Rotary Independent Copter Hybrid*) is the result of our autonomous large-scale three dimensional scanner. The scope of the project rests mostly on designing a functioning quad-copter capable of sustaining the weight of all instruments on board, as well as converting the gathered information into a three dimensional model and ensuring that the OSTRICH is autonomous enough to independently scan a large-sized object without necessary human intervention. Note however that some larger components of the project are outside of our scope and will therefore be adapted to function for our specific needs.

Items of functionality that remain in scope are:

1. Designing a quad-copter capable of flight;
2. Manipulating acquired flight controller to allow stable flight
3. Manipulating basic object avoidance system to eliminate possible collisions;
4. Designing a control system capable of automated flight and scans;
5. Designing a launchpad for distance and position locating as well as homing;

6. Assembling basic 3D scanner capable of scanning objects within size limitations
7. Interfacing with 3D model conversion software;
8. Printing scans using a 3D printer;

Items of functionality that remain outside of scope are:

1. Designing a flight controller;
2. Designing a collision avoidance system;
3. Developing 3D model conversion software;
4. Building a 3D printer;

The goal of the OSTRICH is to be generally applicable to a wide range of possible uses for both professionals and hobbyists, depending on the intended applications. These may include surveying small buildings, rendering sculptures/statues, applications for entertainment such as game design or film, researching and studying fragile historical artifacts, and so on.

1.3 Definitions, Acronyms & Abbreviations

Below are definitions, acronyms and abbreviations for specific or uncommon words used in the following document.

3D	In this context, the representation of a three dimensional real-world object in a two dimensional digital environment using geometric data.
fps	Camera's picture rate measured in *frames per second.*
MP	A *megapixel* refers to the size of an image in reference to a photo from a digital camera.
Modular Component	A component of the OSTRICH which is designed to be easily removable, repairable or replaceable. Most of the OSTRICH's outer hull constitutes as a Modular Component.
Non-Modular Component	A component of the OSTRICH which cannot be removed, replaced, or repaired with ease.
ppi	Camera's image resolution measured in *pixels per inch.*
Quad-copter	A helicopter-like vehicle propelled by four rotors. In this context, it is relatively small and manageable by a single person.
OSTRICH	Our project name abbreviation which stands for *Object Scanning Tetra Rotary Independent Copter Hybrid.*
*	A red asterisk denotes requirements that are liable to change during the development process.

1.4 References

1. "Flying an Unmanned Aircraft for Work or Research." Government of Canada; Transport Canada; Safety and Security Group, Civil Aviation. Web. 2 Nov. 2015.

2. "Advisory Circular (AC) No. 600-004." Government of Canada; Transport Canada; Safety and Security Group, Civil Aviation. 6 Jan. 2015. Web. 2 Nov. 2015.

1.5 System Overview

1.5.1 Context Diagram

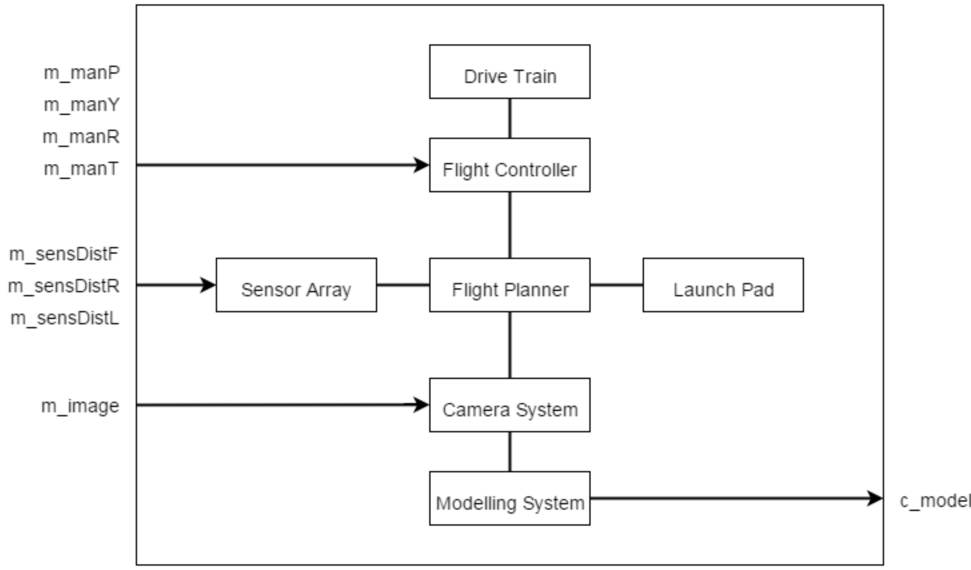

Figure 1: Context diagram for OSTRICH system

1.5.2 Monitored & Controlled Variables

The monitor and control variables, as deemed necessary for the system to function properly according to system requirements, are listed in the below tables.

Variable	Description	Range	Units
`m_manP`	Manually controlled pitch (override)	0 - 90 ± 5	deg
`m_manR`	Manually controlled roll (override)	0 - 90 ± 5	deg
`m_manY`	Manually controlled yaw (override)	0 - 360 ± 10	deg
`m_manT`	Manually controlled thrust (override)	0 - 0.5 ± 0.05	N
`m_DistR`	Distance from object on right	0 - 6 ± 0.1	m
`m_DistL`	Distance from object on left	0 - 6 ± 0.1	m
`m_DistF`	Distance from object in front	0 - 6 ± 0.1	m
`m_PX`	Position of the quad-copter on the x-axis	0 - 10 ± 0.2	m
`m_PY`	Position of the quad-copter on the y-axis	0 - 10 ± 0.2	m
`m_PZ`	Position of the quad-copter on the z-axis	0 - 10 ± 0.2	m
`m_BatV`	Current battery voltage	0 - 12 ± 0.2	V
`m_BatI`	Current battery current	0 - 25 ± 0.2	A
`m_Image`	Light reflection captured by camera	N/A	N/A

Table 1: Monitored System Variables

Variable	Description	Range	Units
`c_Pitch`	Tilting about the x-axis	0 - 90 ± 5	deg
`c_Roll`	Tilting about the y-axis	0 - 90 ± 5	deg
`c_Yaw`	Twist or oscillate about the z-axis	0 - 360 ± 10	deg
`c_Thrust`	Upward thrust exerted by the motors	0 - 0.5 ± 0.05	N
`c_CamIO`	Camera operation on or off	0 or 1	Binary
`c_State`	Current state of the system	N/A	Enum
`c_Timer`	Current timer count	0 - $(2^{32} - 1)$	s
`c_OX`	Original position of quad-copter at the start of scan, x dimension.	0-12 ± 0.2	s
`c_OY`	Original position of quad-copter at the start of scan, y dimension.	0-12 ± 0.2	s

Table 2: Controlled System Variables

1.5.3 Constants

Constants relating to the system in order for it to function properly according to the requirements are listed in the below table.

CONSTANT	DESCRIPTION	VALUE	UNITS
`k_FrameRate`	Frame rate of the camera	1	fps
`k_CamRes`	Camera resolution	5	MP
`k_TotalMass`	Mass of the OSTRICH	2*	kg
`k_TotalHeight`	Height of the OSTRICH	20*	cm
`k_TotalWidth`	Width of the OSTRICH	30*	cm
`k_TotalDepth`	Depth of the OSTRICH	30*	cm
`k_Storage`	Maximum solid state storage capacity	8*	GB
`k_MaxSpeed`	Maximum horizontal velocity of quad-copter	1	m/s
`k_DistTol`	Maximum positional error of a complete loop around scanning object	0.05*	m

Table 3: Constants of the System

1.5.4 Functional Decomposition

The operation of the quad-copter will be in three phases of Takeoff, Scanning, and Landing.

During the takeoff phase, the quad-copter will take initial measurements of battery voltage and current as well as take distance readings to ensure that all sensors are working properly. The quad-copter will slowly spin up the motors and ascend to a desired initial elevation. After it reaches this elevation, the quad-copter will approach the object to be scanned until it reaches the optimal distance away from the object.

During the scanning phase, the quad-copter will take photos of the object at set intervals on a path around the object. This path is planned in real-time and aims to keep a constant distance from the camera to the face of the object. When the quad-copter completes a circuit around the object, it will increase it's elevation and begin taking photos around the object. After the quad-copter finishes its final circuit around the object, it will move on to the landing phase. The behaviour of the scanning phase is outlined in figure 2.

In the landing phase, the quad-copter will travel a wider orbit around the object while searching for the area in which it took off from. Upon finding this area, the quad-copter will slowly descend until it reaches the ground, at which point it will turn off its motors and open the battery relay, effectively turning off the quad-copter.

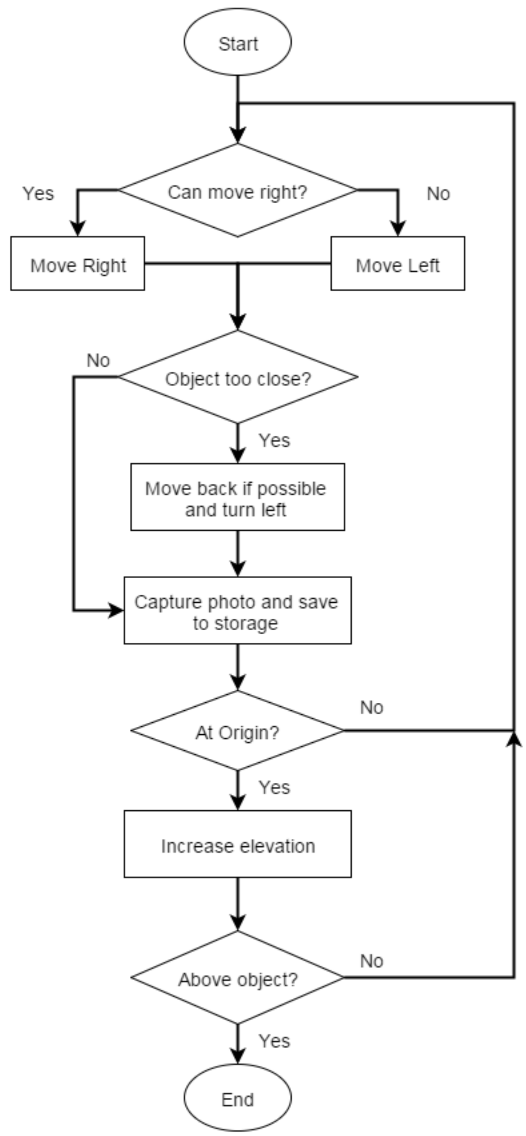

Figure 2: Flowchart of scanning phase*

2 General System Description

2.1 System Context

The OSTRICH is designed to autonomously scan and compose a 3D model of an opaque and somewhat convex object whose size is larger than is ideally reachable by a human user. The OSTRICH is intended for outdoor use provided that the OSTRICH is not to be exposed to extreme or otherwise detrimental weather conditions such as rain or heavy wind speeds, as well as indoor use provided that the room in which it is operational contains sufficient space to allow the OSTRICH to complete its operational cycle as specified within this document.

2.2 System Modes and States

Mode	Description
`SYSTEM_OFF`	The state wherein the battery is not feeding power to the rest of the system.
`SYSTEM_INIT`	The state wherein the quad-copter first lifts off and finds the object in front of it to scan.
`SYSTEM_SCAN`	The state wherein the quad-copter is moving horizontally along the object being scanned, and the camera is taking pictures at set intervals.
`SYSTEM_TAKEOFF`	The state wherein the quad-copter moves vertically to a height where scanning begins.
`SYSTEM_LAND`	The state wherein the quad-copter is attempting to land at its starting point, and shuts down.
`SYSTEM_FAILURE`	The state wherein the 3D scanning operation has failed in some capacity.
`SYSTEM_E_LANDING`	The state wherein the quad-copter attempts to land at whatever position it is currently at, and shuts down.
`SYSTEM_E_SHUTDOWN`	The state wherein the quad-copter immediately performs a shut down operation.
`SYSTEM_ABORT`	The state wherein the quad-copter cannot begin the scanning operation, and shuts down.
`SYSTEM_MANUAL_CONTROL`	The state wherein the user assumes control of the quad-copter using a remote control.

Table 4: System Modes and States*

2.3 Major System Capabilities and Conditions

The OSTRICH is designed to autonomously scan and compose a 3D model of an opaque and somewhat convex object whose size is larger than is ideally reachable by a human user. The OSTRICH is intended for outdoor use provided that the OSTRICH is not to be exposed to extreme or otherwise detrimental weather conditions such as rain or heavy wind speeds, as well as indoor use provided that the room in which it is operational in contains sufficient space to allow the OSTRICH to complete its operational cycle as specified within this document.

MC1 In order to execute the scanning procedure, the quad-copter will find the object in front of it during the initialization sequence and begin the scan operation. It will abort the operation based on the following condition is met: object detected by the front sensor,

Monitored variables: `m_DistF`

Controlled variables: `c_State`

Constants: N/A

Mathematical Representation:

CONDITION	OUTCOME
`m_DistF==NaN`	`c_State=SYSTEM_ABORT`
`m_DistF!=NaN`	`c_State=SYSTEM_SCAN`

Table 5: 2.3.1 Condition Table

MC2 To ensure the safety of bystanders, operators, and the device, as well as to allow the system to be able to meet many other quad-copter related constraints and requirements, the quad-copter must be able to achieve sustained flight during the SYSTEM_SCAN, SYSTEM_CHECK, SYSTEM_FAILURE, and SYSTEM_MANUAL_CONTROL states.

Monitored variables: `m_PZ`

Controlled variables: `c_VZ, c_State`

Constants: N/A

Mathematical Representation:

CONDITION	OUTCOME
`c_State == (SYSTEM_SCAN || SYSTEM_CHECK || SYSTEM_FAILURE || SYSTEM_MANUAL_CONTROL)`	`(c_VZ = 0)&&(m_PZ = 0)`

Table 6: 2.3.2 Condition Table

MC3 The quad-copter must be able to keep level during flight, regardless of outside disturbances.

Monitored variables: N/A

Controlled variables: `c_Pitch, c_Roll`

Constants: N/A.

Mathematical Representation: `c_Pitch`= 0 ± 0.1 m, `c_Roll`= 0 ± 0.1 m

Condition	Outcome
ALL STATES	N/A

Table 7: 2.3.3 Condition Table

MC4 The quad-copter must be able to move at a predetermined speed horizontally and vertically, and stop when the camera must take a picture. This ensures control of the quad-copter is maintained, and that camera performance is not hindered.

Monitored variables: N/A

Controlled variables: c_VX, c_VY, c_State, c_Timer

Constants: N/A

Mathematical Representation:

Condition	Outcome
(c_State==SYSTEM_SCAN)&&(c_Timer mod k_FrameRate == 0)	(c_VX = 0)&&(c_VY = 0)
(c_State==SYSTEM_SCAN)&&(c_Timer mod k_FrameRate != 0)	$\sqrt{c\_VX^2 + c\_VY^2} = k\_MaxSpeed$

Table 8: 2.3.4 Condition Table

MC5 In order for the camera module to produce sufficient images to generate a 3d model, the camera on the quad-copter must take pictures at a set interval when the current mode is SYSTEM_SCAN.

Monitored variables: N/A

Controlled variables: c_CamIO, c_Timer, c_State

Constants: N/A

Mathematical Representation:

Condition	Outcome
(c_State==SYSTEM_SCAN)&&(c_Timermod k_FrameRate=0)	c_CamIO=1
(c_State==SYSTEM_SCAN)&&(c_Timermod k_FrameRate =0)	c_CamIO=0

Table 9: 2.3.5 Condition Table

MC6 The quad-copter must be able to move around an object one full orbit in a single direction such that the pictures being taken by the camera are usable to render a 3D model.

Monitored variables: m_PX,m_PY,m_OX,m_OY

Controlled variables: m_VX,m_VY

Constants: k_DistTol

Mathematical Representation:

Condition	Outcome
(c_State==SYSTEM_SCAN)&&($\sqrt{\text{m\_PX} - \text{m\_OX})^2 + (\text{m\_PY} - \text{m\_OY})^2} \leq$ k_DistTol)	c_State=SYSTEM_RISE

Table 10: 2.3.6 Condition Table

MC7 To encure the quad-copter's continued longevity, the quad-copter must be able to safely land without damaging any of its parts, and thus must move towards the ground at a suitably low velocity.

Monitored variables: N/A

Controlled variables: `c_VZ`

Constants: N/A

Mathematical Representation:

Condition	Outcome
c_State==(SYSTEM_LAND)	c_VZ<0.1

Table 11: 2.3.7 Condition Table

MC8 In order to determine when the quad-copter has finished the scanning procedure, the quad-copter must be able to detect the top of the object it is scanning, and note that the scan is complete. This is determined by the sensor being above the top of the object and not sensing anything.

Monitored variables: `m_PZ,m_DistF`

Controlled variables: `c_State`

Constants: N/A

Mathematical Representation:

Condition	Outcome
(c_State==SYSTEM_RISE)&&(m_DistF==NaN)	c_State=SYSTEM_LAND

Table 12: 2.3.8 Condition Table

MC9 To ensure the safety of both the object and the quad-copter, the quad-copter must be able to avoid collisions with the object it is scanning, be keeping a certain distance away from all surfaces on the front, left, and right side.

Monitored variables: `m_DistL,m_DistR,m_DistF`

Controlled variables: N/A

Constants: N/A

Mathematical Representation:

Condition	Outcome
All States	`(m_DistR < 2)&&(m_DistL < 2)&&(m_DistF < 2)`

Table 13: 2.3.9 Condition Table

MC10 The quad-copter must be able to keep a set distance away from the object it is scanning, to keep images consistent.

Monitored variables: `m_DistF`

Controlled variables: `c_State`

Constants: N/A

Mathematical Representation:

Condition	Outcome
`c_State==SYSTEM_SCAN`	($m\_DistF = 2$)

Table 14: 2.3.10 Condition Table

2.4 Major System Constraints

MC11 To prevent collisions, the speed at which the quad-copter is moving must be below such a speed that the sensor will be able to detect an impending collision and the flight controller will be able to avoid said collision.

MC12 The speed at which the quad-copter is moving must be below such a speed that the pictures taken by the camera will be able to be stitched together to make a 3D model. In essence, that the pictures taken while the quad-copter is orbiting the object must have some amount of overlap such that the images can be stitched together.

MC13 During the rise step, the quad-copter must not rise so far as to miss parts of the object for the scan. In essence, that the picture being taken from a certain distance up must not have zero overlap with the picture taken right above it, so that images can be stitched together.

MC14 The manual off switch of the quad-copter must be out of the way of the propellers, such that a user will not injure themselves trying to turn it off.

2.5 User Characteristics

2.5.1 Hobbyist

Hobbyist will use OSTRICH to create 3D models of scans for personal use.

2.5.2 Professional

Users in the professional field can use OSTRICH to scan objects of any sort. In the insurance field, OSTRICH can be used to scan cars or homes for any exterior damage. This will allow insurance companies to have a better record of customer claims. OSTRICH can also be used for quality inspection. It will allow the user to have OSTRICH scan sections of an object that cannot be easily reached by man.

2.6 Assumptions & Dependencies

AD1 The shapes to be scanned are not irregular

AD2 The objects must be relatively opaque in order to scan

AD3 OSTRICH must be able to scan an object at a maximum of a specified length, width and height

AD4 OSTRICH can only be run when the weather is clear. The OSTRICH will not function in precipitation or moderate to heavy winds.

AD5 OSTRICH can only be started from the take off/landing pad

AD6 Any operator of OSTRICH must be aware of its functionality before use

AD7 OSTRICH must have a clear space in order for it to take off and land

AD8 Any person around the take off and landing pad must be 1 meter away before OSTRICH takes off and lands

AD9 All non-modular components are assumed to be durable enough to survive the life time of the drone

AD10 OSTRICH can only store 8GB worth of scans in one scan cycle before it runs out of storage space

2.7 Operational Scenarios & Formal Representation

SR1 Regular flight scenario - In the regular flight scenario, the OSTRICH is set to take off from the launch pad and begin its scan. While in the air, OSTRICH will use its launch pad as a point of reference to start and finish its orbit. When the scanning is done, OSTRICH will land back on the launch pad and shut down.

SR2 Low battery scenario - In the low battery scenario, if the OSTRICH is in the middle of a flight, it will slowly be directed to land in order to avoid any damages or injuries.

SR3 Abort scenario - In the abort scenario, if the OSTRICH deviates from typical start up, the OSTRICH will be able to initiate abort on the quad-copter before any further problems occur.

SR4 Emergency shutdown scenario - In the emergency shutdown scenario, if OSTRICH is in the middle of a flight and in case of complications, such as instability or imminent collision, the user will be able to command the OSTRICH to land. This will result in the OSTRICH's abrupt cessation of activities and will return with a safe landing. The user will be able to emergency shutdown from the landing pad.

3 System Capabilities, Conditions & Constraints

3.1 Physical

PH1 To minimize costs most of the inner components of the OSTRICH as well as sensitive components should be non-modular while the outer components should be modular as they are more likely to be damaged and need replacement.

PH2 The construction of every aspect and component of the quad-copter and sensor components should be approved or overseen by someone with mechanical expertise.

PH3 To minimize the quad-copter, modular components should be composed of a plastic or plastic-like material which should be cheap enough to replace on an undergrad student's budget and durable enough to not need to be replaced more often than twice per month when under expected conditions.

PH4 To maximize the longevity of the quad-copter, non-modular components should be durable enough to withstand an unexpected collision at the quad-copter's maximum expected velocity.

PH5 To both minimize costs and maximize longevity of the quad-copter, non-modular components should not need replacement or extensive repair due to wearing out within expected operational constraints over the effective lifespan of the project.

PH6 Modular components should be easily removed and replaceable.

PH7 To guarantee some level of system robustness, the quad-copter should be able to navigate around somewhat irregular shapes provided that they are still relatively opaque and convex in colour and shape, respectively.

PH8 The quad-copter is intended for operation in clear and temperate weather with little wind speed present.

PH9 To guarantee some level of system robustness, the quad-copter should be able to operate within rooms large enough to contain the object of choice with relatively few irregularly shaped obstructions surrounding it.

3.2 System Performance Characteristics

SC1 The OSTRICH should be able to accurately capture and stitch a sequence of images together or resolutions no lower than 480p but no higher than 1080p. This will ensure a minimum accepted level of detail for the 3D model, while also placing a boundary on image processing times.

SC2 The quad-copter should be able to consistently maintain flight speeds and should not travel at any speeds exceeding it's maximum allotted speed.

3.3 System Security

SS1 To offer some form of data transmition security, all wirelessly transmitted information and commands should either use some form of data encryption or adhere to a data transmission protocol of the design team's choosing.

3.4 Information Management

IM1 Any and all image files accumulated through the OSTRICH's designed use should be stored on a removable SD-card which will be interfaced with the OSTRICH during intended use. This is done so to avoid straining the processors.

IM2 All of the image-stitching related image processing should be performed on board of the OSTRICH in non-real time operation. This is done so to ensure that while the quad-copter is executing the scanning algorithm, it does not lose priority to the processing intensive image processing.

3.5 System Operations

SO1 The OSTRICH should be largely autonomous and should require minimal human interaction for it to accomplish its intended functions.

SO2 Expected operators and bystanders of the OSTRICH should be aware of its location and operation as well as being wary of coming into unexpected contact with it while in operation.

SO3 All modular components should be designed to be easily removable and replaceable in order to maintain the integrity of the OSTRICH's outer hull.

SO4 The OSTRICH should have a powerful enough battery to power it for the entirety of at the minimum a single operational task, from start to finish. This ensures that the OSTRICH can complete an operational task without needing to be recharged.

SO5 to maximize longevity any and all non-modular components, as well as some modular components should be designed or positioned such that they may withstand an unexpected collision at the quad-copter's maximum expected velocity.

3.6 Policy & Regulation

PR1 The quad-copter will weigh less than 2 kg, allowing it to fly as outlined by Transport Canada without necessary permission - Flying an unmanned aircraft for work or research [see reference 1].

PR2 To ensure legal operation, the OSTRICH will adhere to all relevant safety guidelines outlined by the Canadian Aviation Regulations.

PR3 To ensure legal operation, the OSTRICH will comply with any relevant sections of the Criminal Code and any municipal, provincial and territorial laws relating to the trespassing. Please note, that invasion of privacy or the use of this product for surveillance will fall under trespassing.

PR4 To ensure legal operation, the OSTRICH will comply to all applicable sections "Advisory Circular No. 600-004 - Guidance Material for Operating Unmanned Air Vehicle Systems under an Exemption" [see reference 2].

PR5 OSTRICH will allow user overriding of autonomous features such that it complies with section 4.2 subsection 31 of the Guidance Material for Operating Unmanned Air Vehicle Systems under an Exemption.

PR6 The quad-copter falls under the policies and regulations of Advisory Circular No. 600-004 - Guidance Material for Operating Unmanned Air Vehicle Systems under an Exemption because it satisfies the requirements noted in section 1.3 which is in regards to applicability.

PR7 In particular, OSTRICH will comply with all subsections of 4.1 - General Conditions. Some of these subsections involve the user and as such the user will have to comply with these subsections as they are in regards to not only the safety of the user but the public as well.

3.7 Life Cycle Sustainability

As stated above the construction of the OSTRICH will involve modular and non modular components. The modular components will be of a cheaper material as they may need to be replaced. The non modular components should be durable much longer than the modular components. In the event that modular components require replacement, it should be simple to order new components and replace any failed components.

During the development of the OSTRICH, it will be subjected to rigorous testing and thus modularity is a key cornerstone of the design. This is because in the event of a failure, any component that breaks or fails needs to be replaced with a working component without taking everything apart.

LCS1 Moderate technical understanding of the OSTRICH will be required for replacement of components.

LCS2 Replacing of modular parts should take no longer than 1 hour and 30 minutes.

LCS3 Modular components must have a minimum expected life of 15 days when under expected conditions.

LCS4 to maximize longevity non modular components should be able to withstand small to medium impact collisions without failure.

LCS5 Failed modular components should be disposed of in a sustainable manner as they will be made of plastic or similar material.

LCS6 Patches can be introduced to fix any bugs or faults in the software component.

LCS7 Many of the modular components can be 3D printed. The models for these components will be provided.*

LCS8 To minimize the costs of the project, the non modular components will have an expected life of 8 months under expected conditions.

4 System Interfaces

The OSTRICH has two major systems that will interact with one another, the hardware/software component on the quad-copter and the hardware/software on the landing pad.

The quad-copter component will be receiving and sending radio signals to the landing pad*. On board the different components of the quad-copter will interact with one another in order to ensure all requirements are met. This will involve sensors interacting with the on board flight controller to ensure that the quad-copter is stable and avoiding any obstacles that might lead to a collision. The sensors will also ensure that a respectable distance is established from the object being scanned. In the event that there is no object present in front of the quad-copter it will also abort the scanning operation. The camera will be interfacing with an on board Arduino which will store images to an SD card. It will also be responsible for notifying the flight controller that the landing pad is directly below the quad-copter. Finally, the flight controller will be responsible for interacting with all the hardware on the quad-copter. It will be responsible for all actions concerning the motors; including any emergency protocols such as an emergency shutdown. The emergency shutdown button on board will be responsible for interacting with the flight controller and turning the power for the quad-copter off. That concludes the interactions between the components on board the quad-copter.

The landing pad will be interacting with the flight controller by sending radio signals that will communicate if the quad-copter is ready for take off. It will also a button that sends an emergency landing signal. That concludes the system interfaces in regards to the landing pad.

5 Items Likely to Change

This section will briefly explain all of the items in the requirements document that are more likely to change than anything else. All items that are considered "likely to change" are marked by a red asterisk throughout the document, and the rationale for these items will be listed here.

1. Constants k_TotalMass, k_TotalHeight, k_TotalWidth, k_TotalDepth, and k_Storage are deemed likely to change, as we have written preliminary values for said constants, but the actual hardware for the size of the OSTRICH's frame are liable to change based on testing.

2. The scanning phase algorithm is also listed as likely to change. As testing is performed, it may be that to complete the scanning phase the algorithm will have to be modified.

3. It is predicted that this is not a conclusive and final list of all system states, and that more distinct states may be deemed necessary as the system is designed.

4. The launchpad and its implementation and use are things that are likely to change. Currently it functions as more or less a placeholder for a starting point for the launch, and a device through which to send instructions such as an emergency stop for the quad-copter.