Computer science project report

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August 2, 2022

Contents

Chapter 1

Analysis

1.1 Outline

Photogrammetry is a process where a series of overlapping images are analysed to extract 3 dimensional data about the subjects of the images, this data can then be used to produce 3D models which can be used in games and CGI for movies, or 3D printed to produce a replica. This project aims to produce a piece of software which can be used to process videos for use in photogrammetry software, with a focus on ensuring ease of use with popular open source options.

The general process of photogrammetry involves taking a series of individual images of the object. The issue with this is that taking a picture, moving the camera around the object, and repeating can be very time consuming. Taking a video of the object is much easier, as one can simply walk around the object with the camera pointed at it.

The problem of needing individual images become especially difficult when doing drone-based photogrammetry, for similar reasons to those described above.

1.2 Identification of all stakeholders

1.2.1 Stakeholders

The client for this project is Mr.Parr, one of my computer science and IT teachers.

The end users of this project include myself, Mr.Parr, and potentially some people on the internet who do photogrammetry, as there are some posts on the internet where individuals have complained about existing solutions, so it is likely that they would be interested in my alternative (see section 1.3).

1.2.2 Stakeholder descriptions

Myself: i occasionally do 3D modelling in my spare time, sometimes involving photogrammetry.

Mr.Parr: Wannabe game dev or something.

Internet people: This group of people who may be interested in using this software is very broad, but generally it is more likely that they will not be professionals and will make use of open source software more often that proprietary software, this is due to the fact that my existing (small, but existing) youtube audience is compromised entirely of blender users. I will be showcasing this software on my youtube channel mainly, but i may showcase it on other websites

1.2.3 How stakeholders will make use of proposed solution

I would use this software occasionally for personal photogrammetry projects. It would be appropriate for my personal projects as i would prefer to use an easy and efficient piece of software to convert captured videos into usable image data.

Mr.Parr has described why he needs this software produced:

> "I would like to be able to use my phone and drone to use the video capture option instead of taking many still images. As the delay between pressing the button and capturing the image can cause issues. It means I could focus on flying/walking/moving smoothly and extract image later"

Essentially Mr.Parr will be using this software primarily for hobby purposes, he will use this software to speed up the process of creating 3D models from videos, saving his precious time to focus on the more important aspects of his projects.

Users on the internet may use this project for photogrammetry projects where they have or would prefer to capture video footage as the source data. My software could be more appropriate than existing methods and this is evidenced by the fact i have seen individuals complain about the current existing solutions and methods for performing the task of converting video into image data usable for photogrammetry.

1.2.4 Why the proposed solution is suitable for the stakeholders needs

The proposed solution will be well suited to my needs as the development will be guided partly by my personal preferences when there is no information given by the client for the particular part of the program being developed. A lot of the features of the program are suggestions to the client from myself, based on what i would i believe is required to create the most optimal image dataset from a given video for the process of photogrammetry.

The proposed solution will be suitable for the needs of the client as I intend on writing the program in such a way that it performs all the basic tasks he originally asked for, as well as more advanced functions that I believe could be very useful. The basic requirements outlined by the client can be achieved reasonably easily (see section 1.4), and I am sure that I will meet these requirements reasonably early on in development. Meeting all the client requirements will most likely result in the software suitably solving the problem, but I want to make sure that the software solves issues which the client may not even be aware of, and I will do this by including features which solve issues I have personally had with photogrammetry.

It is harder to be sure that the proposed solution can solve issues which "people on the internet" have. I believe there are people who will make use of my software, although I am not sure how many people will make use of it and how exactly they will make use of it.

1.3 Research

1.3.1 Previous personal experience

I have personally performed photogrammetry multiple times, this will be greatly beneficial to this project as it means i already have some idea of

what is required from the software being produced. My previous experience with photogrammetry allows me to introduce various additions to the project not explicitly outlined by the client which i know will be beneficial. Some of these additions include image denoising, removing bad data, etc.

This previous experience with photogrammetry will likely prove to be incredibly useful during development. Already knowing about the process of photogrammetry and what is required of the input data to produce a good 3D scan will help massively.

From my previous experience with photogrammetry I know that the input data must have the following qualities:

- Reasonably high resolution is required as it produces more accurate geometry and greater texture resolution on the 3D model.
- Images need to be free of blur, for essentially the same reasons image resolution is important; geometry accuracy and texture resolution.
- Images must have some overlap with each other, as in there must be an obvious link between two images of the same object. This is because the photogrammetry software builds a mathematical model of objects by first discovering matching points across images, then figuring out their positions in 3D space by comparing the different views of the points across the images.

1.3.2 Video photogrammetry research

Being able to produce 3D models from video has many advantages over having to manually capture images individually, the main one being the fact it can save a considerable amount of time. Video capture can also be useful for drone photogrammetry.

Extracting images from video does certainly have its downsides, after doing a bit of searching around and reading other peoples experience with using video for photogrammetry, i found the following potential issues:

- Frames extracted from videos are often much noisier than images captured manually, this is due to the much shorter exposure time requiring a higher ISO. This noise can then show up in the final textures generated for the 3D model, which is of course not ideal.

- Frames extracted from videos can often be blurrier, this is due to the fact that video files are compressed to a much greater extent. Videos can also be blurry due to the way the person capturing the video moves.

1.3.3 Existing discussion of the problem

Some individuals have discussed the need for such a program on the internet. Put some more stuff about that here! Fuck where did that reddit post go

1.3.4 Existing solutions

Most generic video editing software is capable of outputting frames from an input video, but the process is not optimised for ease and speed of use. Often, users may have to dig through many different menus and settings to output a certain amount of frames from the input video. These solutions also do not offer the ability to automatically detect and remove problematic frames from the extracted dataset.

One open source piece of software capable of outputting frames from an input video is blender. Using the "step" option the user can choose to skip over a certain amount of frames, so for example, they could output one frame from every 10 in the input video. A more advanced blender user will also know that image denoising can also be performed inside blender. The downside to using this piece of software is that it has a very dense user interface, making it time consuming to find the options required to set up frame extraction. It is also not capable of the advanced features which my software will include, such as blur detection and removal, and image similarity measurement.

Another open source piece of software capable of extracting frames from a video is FFMPEG. FFMPEG is a command-line tool which can be used for the editing or processing of videos, it is especially useful for producing scripts which automate video editing or processing tasks. FFMPEG is not at all easy to use, and is not suitable for the client. But it could be of use to me, as I could use the FFMPEG library in my code to perform video manipulation functions (it could be faster than openCV for certain tasks).

Another open source solution capable of outputting frames from an input video is shotcut. Shotcut allows a simple conversion of video input into still

image output, but is very limited and not particularly easy to use. My software will include many more relevant features compared to shotcut.

One of the solutions previously used by the client is VLC media player, this piece of software is capable of frame extraction at fixed steps but is not easy or quick to use. The settings that need to be adjusted to output frames from an input video is hidden deep inside the settings.

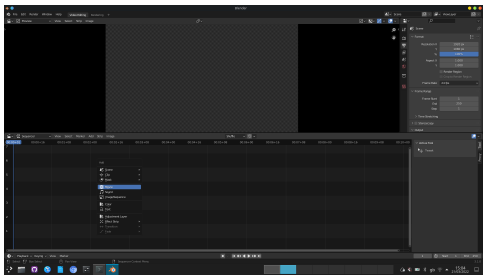


Figure 1.1: Blender video editor

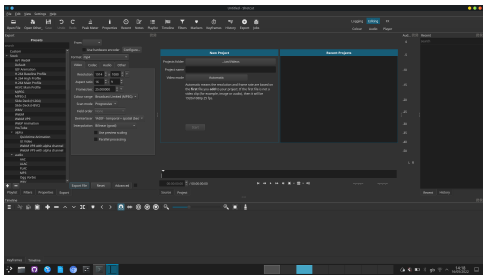


Figure 1.2: Shotcut video editor

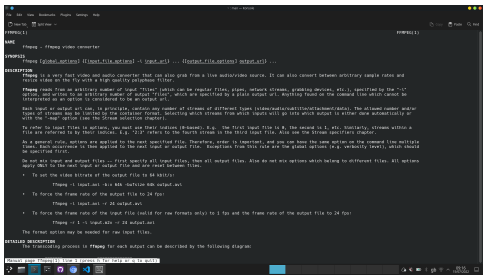


Figure 1.3: FFMPEG man page

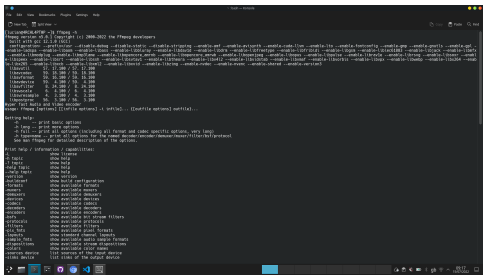


Figure 1.4: FFMPEG

All these existing solutions do cover the main client requirement; Converting a video into a set of images. But the primary issue with them is how they are not particularly user friendly, the fact it takes too long to set up VLC to perform image extraction is the main reason the client has the need for a custom solution. These pieces of software all demonstrate the fact that simply performing the task on the most basic level required is not sufficient, it must be easy for the user to learn how to use the software and it must be a quick and simple process once they have learnt how to perform it.

1.3.5 Client feedback/question

Question	Client answer
1: How will you make use of this program?	I would like to be able to use my phone and drone to use the video capture option instead of taking many still images. As the delay between pressing the button and capturing the image can cause issues. It means I could focus on flying/walking/moving smoothly and extract image later. (example photos are available)
2: What exactly do you absolutely need this software to do? (what are the minimum requirements for the software to be viable?)	• Input a video • select output folder • select filename • Program auto add a unique number i.e. castle0001 (prefix zeros essential) - Prefix could be calculated by working out number of frames from length of video • Select frequency of images to be captured i.e. 1 per second or every 5 frames • Choose file format i.e. jpeg, png, bmp etc • Choose custom image size, source size should be default • User friendly GUI – intuitive to use - Should take a new user less than a minute to figure out.
3: What current software/processes do you use which will be replaced by this program? Bonus: why do you need to replace them?	Currently resort to just doing individual image on the camera. I have used vlc video player – it is a faff, you have to use the options deep in the setting menu to auto export images. It then does it to every video you play. I have seen blender used, again, not user friendly, not quick or intuitive. I have not research blender options.
4: Which takes greater priority: ease of use vs ability to tweak final result to get optimal results? Bonus: why?	Ease of use. If its hard, it wont get used at all.
5: Which takes greater priority: optimising RAM usage vs optimising computational time taken? Bonus: why?	Actual processing time is not a concern, as 3d scanning is lengthy anyway. Calculating harddrive space could be useful though. I hate starting a job, then computer says half way through, not enough space. It would have taken a simple algorithm to do a quick pre check.
6: Are the outlined success criteria relevant (see lower section)? If not please describe additions or changes that should be made.	Yes, but reflect on above comments.

Reasons for each question
1: Understanding how the client will utilise the program is essential to know exactly how it should be designed and developed to meet their requirements. If i do not have a direct description of how the client plans to utilise this software, i would have to simply guess when making important decisions about the design.
2: Similar to the first question, i need to know what is required to produce the minimum viable product for the client. Knowing this will allow me to prioritise features.
3: Understanding why the clients existing solutions need to be replaced will help me design software which focuses on improving the areas the client had specific issues with when using other existing solutions.
4: Knowing this will allow me to optimise the design to the client and their required level of complexity in terms of software customisability and stuff.
5: This specific choice of optimisation needs to be known right from the beginning, throughout implementation decisions need to be made relating to this specific question. Since video/image data is being processed, RAM usage will likely be very high without significant optimisation.
6: It is very important that the success criteria i have described align with the clients own vision of how the software should work and what it should do.

1.4 Essential features of proposed solution

The absolute bare minimum requirements of the software were outlined by the client when i asked. These basic requirements are:

- Input a video (Take a video on disk as input, read it into memory/temp file)
- Select output folder (User can choose where the output of the program will go)
- Select filename (User can choose the name of the output files)
- Program auto add a unique number i.e. castle0001, prefix zeros ESSENTIAL (Output files have number representing frame number)
- Select frequency of images to be captured i.e. 1 per second or every 5 frames (Let user choose the rate at which frames are saved out of the input video)
- Choose custom image size, source size should be default (User can choose to resize the output frames, by default dont resize images)
- User friendly GUI - intuitive to use - Should take a new user less than a minute to figure out.

Other essential features which i have decided must be included based on my previous experience with photogrammetry, as well as general requirements which i think should be included even though the client has not named them specifically:

- Can read a variety of different formats of video files, or sets of individual images from a user-specified path on disk.
- Can take user input to change settings.
- Detect and remove images which are too blurry, allowing the user to define the threshold. This feature needs to be included so the user can easily clean up their dataset to improve the quality of the final result of photogrammetry.
- Detect and remove duplicate images, allow user to define the threshold. This feature needs to be included so that duplicate data can be easily removed by the user from their dataset.
- Detect and remove outlier images, allow user to define the threshold. This feature needs to be included so that images which will not be useful for the photogrammetry process can be removed easily.
- Can automatically call specific open source photogrammetry software (meshroom) to start a headless photogrammetry process automatically. This should be included as it will speed up the whole meshroom photogrammetry pipeline for the user.
- Denoise images. This is very important as input video, especially from smartphone cameras, can contain a lot of noise which could negatively affect the result of photogrammetry.
- Minimalistic, easy to use and intuitive graphical interface. This is important as users need to be able to use the software quickly and easily, having an intuitive interface makes it possible for the user to figure out how to use the software for themselves without the need for detailed instructions.
- Settings are grouped into “basic” and “advanced”, by default advanced settings are hidden under a drop down next to the basic settings. This hides functionality that users may be unlikely to need, making it easier to navigate the program and configure the essential settings.

Some the above may need to be able to be toggled on/off by the user depending on their needs.

1.5 Hardware and software requirements

This software will require hardware with reasonable computational ability and capacity, it may be the case that reasonable CPU power and memory space is required to run the data processing on the video input. Faster hardware will result in faster processing of the videos. Available memory could very well be a limiting factor, but determining an exact amount required is not easy as the RAM usage of the program will depend upon the size of the input data. Overall, due to the nature of video and image processing (lots of mathematical operations on a large set of data), it should be expected that a powerful computer will be required.

If possible, i will try and enable GPU acceleration of OpenCV which means that a reasonably powerful GPU may be a hardware requirement. GPU acceleration will likely be added via CUDA and not OpenCL, as i have access to reasonably powerful CUDA capable graphics cards. A CUDA supporting GPU may be a requirement.

I will try and write this software in a way which is cross-platform, so operating system wont be a major limiting factor in what devices can run the software. I will write using a compiled language, so no interpreter will need to be installed to run the software.

1.6 How the problem can be solved by computational methods

1.6.1 Can the problem be solved computationally?

My program primarily performs data processing, processing large amounts of data is a task which naturally can be performed very well on computers. The tasks outlined in section 1.4 can all be broken down into mathematical steps which a computer can perform. Although there may be issues with the time taken to perform these computations, as image processing is very time consuming due to the large amount of data and thus the large number of computations that need to be performed.

1.6.2 Use of abstraction

Representational abstraction can be performed to remove unnecessary details from an idea/concept. Abstraction can be used to simplify a process

to make it easier to use. My program aims to use abstraction to simplify the process of performing:

- Extracting frames from video input
- Denoise extracted frames
- Blur detection/quantification to clean the set of extracted frames
- Comparison of image similarity to remove duplicate images from the set of extracted frames
- Detection of "outlier" images which would clearly provide no benefit during the photogrammetry process
- Running the final cleaned data through meshroom

Simplification of these processes will be done by presenting the user with abstracted controls to guide each process.

For the extraction of frames from video input, the user will be presented with options such as the number of total frames they want extracted from the video, or the desired frames to be extracted per second of video, this is an abstract control of the extraction process as the user does not need to consider the calculation of exactly how many frames to "skip" to get the desired amount of frames from the input.

For the denoising of extracted frames, the user will be presented with a simple control of "denoise strength" (or some other similar name) which allows them to choose how heavily the denoising algorithms will affect the input images without them having to be aware of any of the mathematical processes involved in denoising.

For the blur detection/quantification, the user will simply be presented with a "blurryness" value for each image after the calculations are complete, then they can choose a threshold to filter images out for being too blurry. This abstraction hides away many details about how exactly this "blurryness" value is calculated, the user is just presented with all they need to know about the process of blurry frame removal. The abstracted processes include converting the frames to grayscale, scaling down, and performing calculations such as the variation of the Laplacian filter or Fourier transforms.

For the removal of duplicate/very similar frames, the user will be presented with the option to quickly detect groups of similar images which they can then optionally automatically delete all but one of, or manually view and remove themselves. The process of how image similarity is calculated is completely abstracted and hidden from the user, as they do not need to know about the underlying process of detecting images which may be similar.
Detection of "outlier" images will be presented to the user in a very similar way, but instead of showing them duplicate or very similar images, it will present them with frames which do not match the rest of the data at all (such as completely black frames where the camera was accidentally covered by a finger, for example).

My program will automatically call meshroom for the user if they want it to, which means that as long as they use meshroom they can use my program for their entire 3D scanning pipeline. My program will abstract the process of using meshroom to one or two simple options inside my program.

1.6.3 Required input

My program will require input data, this can be in the format of both video or sets of images. This input data is then cleaned to make it more suitable for use in photogrammetry processes. It must be validated that the input data is of the accepted formats (a variety of image and video formats, jpg, png, mp4, etc).

1.6.4 Procedures and decomposition

The core functionality of my program can very easily be broken down into smaller components, this is because the core functionality exists as a set of procedures performed as individual stages. Each of the following can be completely isolated from one another, then brought together in a main program:

- Reading a video file into frames in memory or in a temp file on disk
- Image similarity comparison
- Outlier detection
- Blur detection
- Image denoising

- Saving the final data to the users desired output location
- Automatically calling meshroom

Each of these isolated components can then also be decomposed further to produce a detailed list of functions the program needs to function.

1.6.5 Concurrence

The main processes will take place in a series of stages, there will not be any concurrent processes aside from the user interface running and displaying information about the progress of the computation and allowing the user to cancel the process.

Running multiple parts of the pipeline at once would likely not result in any speedup as each concurrent process may take CPU/GPU time from the other(s). Additionally, implementing this concurrence would be very time consuming and complex to do in such a way that it actually provides a significant speedup.

1.7 Limitations of proposed solution

A computer with a fairly powerful processor, or (as long as I include openCV GPU acceleration) ideally a powerful GPU will be required to run more intensive functions such as image denoising in a reasonable amount of time.

The fact that video files are often heavily compressed compared to images needs to be considered. Video input simply wont produce 3D scans of equal or better quality than image input, unless professional equipment is used.

Image similarity comparison for duplicate/outlier image removal will likely be a difficult problem to solve, experimentation with various different methods will be required to find a suitable method. Unlike other functions performed inside my software, duplicate/outlier detection is not implemented in libraries such as OpenCV.

1.8 Success criteria

The core success criteria specifically defined by the client, as well as how i can measure them:

- Takes a video input. - Simple to test this, simply define the path to the video in the software and check to see if it loads itself properly into memory or a temp file.
- Output location can be changed by the user. - Very simple to test this, just need to set an output path and check to see if it works.
- Output filename can be customised by the user. - Also very simple to test this, just need to set the output filename and check to see if it works.
- Program automatically appends frame number to the output. - Also very simple to test this, just need to run the software and check the output.
- Frequency of frame extraction can be customised by the user by choosing either frames per second or an amount of frames to 'skip' for every saved frame. - Also a simple test of running the software and verifying the input is correct.
- User can choose to resize the output images (default no resize). - Another simple test which consists of just running the software and verifying the output images are sized correctly.
- User friendly GUI, intuitive to use, Should take a new user less than a minute to figure out. - It is hard to quantify how user friendly and intuitive a GUI is, but the client defines that it "should take a new user less than a minute to figure out", so this metric will be used to measure it.

Additional success criteria specified by myself as additions or clarifications based on my interpretation of the clients feedback and initial requirements:

- Can reliability perform extraction of frames from an input video, and can take user input to control how many frames are extracted. Testing this is simple, send some input video, set the desired amount of output frames, run the function, and compare the output with the desired output.
- Can quantify the "blurryness" of images with a reasonable degree of accuracy. This could be tested by sending a set of clear images and a set of blurry images through the algorithm and comparing the output from each, ideally frames should be classified with a 90% accuracy.

- Can quantify image similarity with a reasonable degree of accuracy. This could be tested by sending pairs of deliberately similar and dissimilar images and comparing how the function quantifies each pair. Exact duplicate images must be detected 100% of the time.
- The process of turning a video into a usable set on images is quicker than existing methods. This should be measured based on a user who is not "used" to any particular piece of software being used, making it a fair comparison of usability. Various different pieces of software should be tested and compared to mine in this way.
- Can reliably remove noise from frames. This could be analysed with the use of test images, a test image can be created/sourced then a "noisy" version of it can be created easily. This noisy image can then be passed through the denoising algorithm then the loss from the original image can be calculated. The mean squared error algorithm (1.1) could be used to calculate this.

$$MSE = \frac{1}{n} \sum_{w,h,c} (y_{w,h,c} - \hat{y}_{w,h,c})^2 \tag{1.1}$$

n = number of data points
y = expected values
$\hat{y}$ = output values
w = represents image width
h = represents image height
c = represents image channels

- The process of extracting frames from videos is faster than using other software. The comparison of speed should also take into account different processing being performed, for example, most video editing software can extract frames from video but not all may be capable of denoising the images. Speed comparisons should be done only when the same output is being produced, making the comparison fair.

Chapter 2

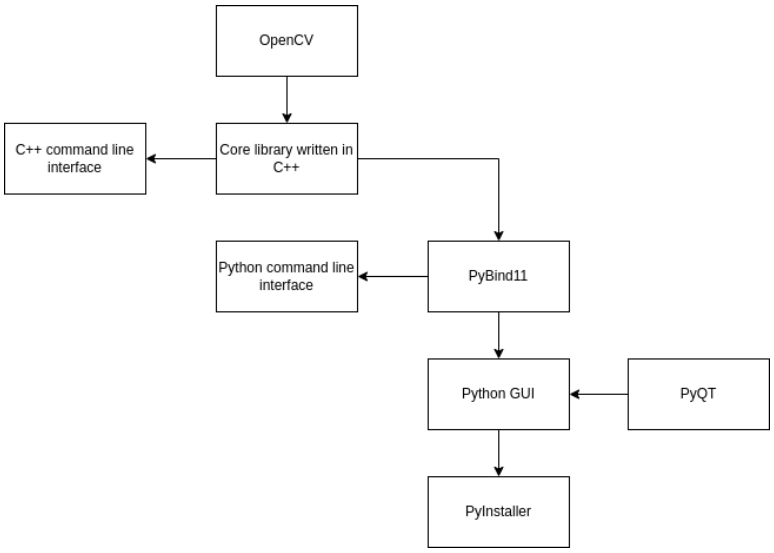
Design

2.1 Structure

2.1.1 Overall solution structure

Figure 2.1 lays out the structure of the solution on a very high level of abstraction.

Figure 2.1: Structure diagram



As can be seen, this program will make use of two languages, as well as a few

libraries and tools. One of the main reasons I have decided to structure my program in this way is the fact it allows me to develop the core functionality and GUI as rather isolated stages of development, which I think will be easier. This structure also allows for much easier cross-platform development thanks to the nature of python.

The following list explains some of the items featured in figure 2.1.

- **OpenCV:** OpenCV is an open source computer vision library, but it contains a great deal of functionality which is useful to very general image processing. OpenCV can be used to extract frames from videos, but also provides many other functions which can be used to enhance the output of the program. OpenCV also supports GPU acceleration using CUDA, which could provide great speed benefits to certain parts of the program.

- **Core library written in C++:** The core functionality of the program will be written in C++. The main reason behind this choice of language is the fact I am already reasonably familiar with the language, which will make development quicker and easier. But C++ is also a good choice in terms of speed due to it being a compiled language, and speed will matter as I will be processing a lot of data.

- **C++ command line interface:** While the final goal of the program is to provide an easy to use graphical user interface, I will be producing a command line interface to the vid2photogrammetry library which I will use during development to quickly perform tests without having to worry about developing the GUI. A command line interface can also be used as part of shell scripts, meaning there is potential for advanced users to integrate vid2photogrammetry into a pipeline of multiple tools/processes.

- **PyBind11:** "pybind11 is a lightweight header-only library that exposes C++ types in Python and vice versa, mainly to create Python bindings of existing C++ code.". I will make use of pybind11 to create an easy to use python module, which can then be compiled for multiple platforms and used in a cross-platform manner very easily. Creating a python module will make cross-platform GUI development much easier, and will allow advanced users to perform advanced scripting of vid2photogrammetry.

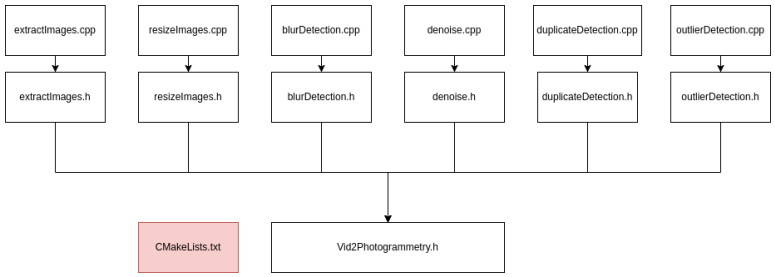
- **Python command line interface:** Similar to the C++ command line interface, but this will exist only for testing purposes. The python command line interface will likely be missing many features compared to the C++ command line interface, as I only plan on making it good enough to test the python module.
- **Python GUI:** Creating the graphical interface for the program using python will make development a somewhat smoother process, as I will not have to worry about compiling C++ code which uses some GUI library (Such as Qt) and OpenCV (Setting up the linking for all this stuff on visual studio on windows gets rather frustrating the first time you do it!). Python makes cross-platform development much easier.
- **PyQT:** "PyQt is a Python binding of the cross-platform GUI toolkit Qt, implemented as a Python plug-in.". I will make use of PyQt as it should be very much capable of providing the features required to produce a GUI for vid2photogrammetry.
- **PyInstaller:** pyinstaller can be used to very easily package a python application into a single package, this package can then be run by the end users without them having to install the python interpreter or any other kind of dependency. I will make use of this to ensure that end-users of the program can access the program very easily. Requiring the end user to install python and any required python modules could cause great inconvenience for them.

2.1.2 C++ library structure

The way I choose to structure the vid2photogrammetry C++ library is important, as I need to ensure it can be used, developed, and maintained very easily. The use of pybind11 also needs to be considered, as the library must be structured in such a way that I can easily create the python bindings. Figure 2.2 shows an overview of the file structure of the C++ library.

There is certainly nothing special about this structure, as the library is pretty small and each piece of functionality can be easily broken up and isolated into different header+source files. The diagram is not a certain and exact definition of how the final structure of the library will look, as I may add additional header and source files to provide extra functionality or avoid duplicate functions across multiple files. It is hard to predict exactly which files will need to exist.

Figure 2.2: C++ library structure diagram



Breaking my library up into a set of header and source files will make maintenance and development easier, as the code be separated out based on what it actually does. This separation will make it much easier to search the library for specific functions.

2.1.3 Python bindings

The python bindings created from the C++ code need to be easy to use, optimised, and well documented for anybody who may want to create custom scripts. This should not be too difficult to achieve, all I need to do is name functions appropriately and write documentation for each of those functions. In terms of optimisation I just need to be careful that I keep all the large image data completely inside the C++ functions, passing lots of data between python and the C++ module could potentially cause some slowdown. The C++ library will require some extra files to make it possible to compile it into a python module, with those extra files the library would look something like figure 2.3

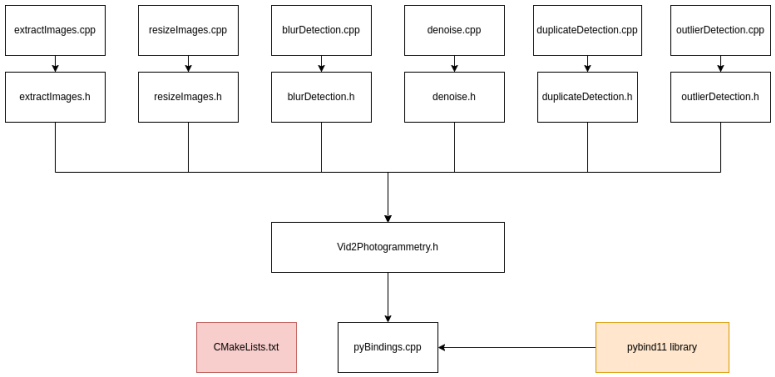
2.2 Decomposition

2.2.1 Overall process

Each image processing function will behave in the following way:

1. Read an image from disk.
2. Process the frame.

Figure 2.3: C++ library structure diagram (with pybind11)



3. Write the frame back to disk.

4. Repeat from step 2 until all frames are processed.

Images are stored on-disk when they are not being used (this saves memory space, at the cost of causing the program to run a bit slower), the fact they are stored on disk also makes it very easy to isolate each stage of data processing. Each 'process' will simply read images, process them, and write images. There is no need to manage variables which store image data outside the scope of each processing function.

Because the processes being performed by the program can be broken down so easily means performing a bit of decomposition during design will be very helpful and easy to do. Having the entire program broken up into smaller pieces which solve individual problems will make it much easier to design and implement the project overall.

2.2.2 A more efficient overall process

While each stage of data processing happening in isolated stages where images are stored temporarily on disk allows for a very easy to understand design to be created, it does mean that there is much more file input/output taking place than there really needs to be. A more optimal way of processing the image data would be to:

1. Read frame from video.

2. Perform **all** the desired processing (resize, blur detect, etc).

3. Write the frame to disk.

If I write the code in a very modular way, it should not be difficult to build this more optimised method from the code for the less optimal solution (this is because I should create a function for each process which takes a cv::Mat as input and gives a cv::Mat as output, file IO should not take place in the same scope as the image processing.).

A drawback to this more optimised process is the fact it would be less flexible, the python bindings would probably end up being reduced to one single entry point binding. This would make the python module more specialised and reduces the opportunities for advanced users to tweak the workflow without compiling any source code.

I will have to assess the significance of the slowdown that extra read/write operations cause, and determine whether or not its worth restructuring the library to reduce this slowdown.

2.2.3 Processes

This subsection will give an overview of the individual processes which need to be performed by the program. The process of breaking down, listing, and describing these individual bits of core functionality will give me a better idea of where to start, what needs to be made, and a starting point for the creation of the algorithms for each process.

I make sure to describe why a process needs to be a part of the program, then I describe the steps that need to be taken (on a very high level of abstraction) to perform the process. I also include any other information I think may be relevant when I refer back to this document during development.

2.2.3.1 User input validation

The program will need to take various types of input from the user. This input includes the input and output filepaths, as well as the configuration for the processes which will be performed on the input data.

To validate filepaths, the following needs to be checked:

- The file or folder exists

- The program has read/write permission (write only required for output folder)
- output folder must be empty

Both of these can be implemented in a simple 'if' statement to ensure that the data processing is only attempted if these two requirements are met. Built-in functions can be used to perform each of the checks.

The configuration inputs will need presence checks and range checks. The presence of configuration will be ensured by creating default values for every setting, although it would be best to be on the safe side and still include validation on any variables taken from GUI input elements.

Input validation should be implemented in both the C++ library and the terminal/graphical user interfaces for maximum resilience against malformed input.

2.2.3.2 Calculating storage space required

One feature specifically mentioned by the client is the program telling the user how much storage space is required for the program to run.

Could be difficult to calculate - but a guess would be good enough, this could be done by calculating the average filesize of a png at the output resolution, and multiplying it by the number of frames the program is going to output.

1. Get output frame count.
2. Get input resolution.
3. Calculate average size of a PNG at the input resolution, using (add description of method above as some kind of formula or something).
4. Multiply the average size calculated with the number of frames to be extracted.

2.2.3.3 Video to image sequence conversion

The primary goal of this program is to convert input images into image sequences which are suitable for use in photogrammetry software. The user must have control over how many frames are extracted from an input video,

extracting every single frame would result in a number of frames which greatly exceeds the number required for photogrammetry, and would not be usable inside the photogrammetry software.

Videos can be converted into image sequences using a variety of different libraries. OpenCV and FFMPEG are the primary candidates for use in my software. The process of extracting frames using either of these libraries will be pretty similar:

1. Create video stream.
2. Skip n frames along stream. (n must be calculated to ensure the desired number of output frames are created)
3. Write frame to disk.
4. Repeat from step 2 until end of stream is reached.

2.2.3.4 Image resizing

Image resolution has a great impact on the time the process of photogrammetry takes. While most photogrammetry software does have image resizing as a built in function, including it in my software will still be useful as it may provide some convenience.

OpenCV can resize images very easily as it has built-in functions which can modify a cv::Mat. The process can be broken down into very simple steps:

1. Load image from disk into cv::Mat.
2. Perform built-in resize function on the cv::Mat.
3. Write cv::Mat back onto the disk.

2.2.3.5 Duplicate image detection/removal

Removing images which are duplicate (or very similar) will speed up the photogrammetry process as the photogrammetry software will not need to process images which do not provide any additional usable data to produce the mesh.

Scaling the image down + converting to grayscale would likely be a first

step to reduce the computational complexity of further steps. Potentially could use general-purpose autoencoders for the next steps.

2.2.3.6 Outlier image detection/removal

Detecting and removing images which are significantly different to the others could help remove really bad frames which the photogrammetry software would reject (such as finger covering up camera).

Detecting these images could maybe be done by analysing the histograms of the images (not sure, no exact plan yet - experimentation required).

Scaling the image down + converting to grayscale would likely be a first step to reduce the computational complexity of further steps. Potentially could use general-purpose autoencoders for the next steps.

2.2.3.7 Blurry image detection/removal

Removing blurry images would help to produce a better quality 3D scan, as blurry images in the dataset result in lower texture and mesh resolution/accuracy.

Detecting how blurry an image is can be done using a couple different methods.

- Variance of laplacian
- Something with fourier transforms

There are two ways i can think of choosing which frames to remove based on how blurry they are:

- Remove frames where the blurryness exceeds some threshold
- Remove the worst n% of frames

Could easily provide the user with the option to choose between these two.

2.2.3.8 Image denoising

Video files can by quite noisy, especially in low light environments (Due to very short shutter speed, high ISO, and stuff idk im not a photographer). Denoising the images before they are used to produce a 3D scan could help

to improve the quality of the textures produced for the 3D scan.

OpenCV has image denoising functionality.

1. Read frame from disk into cv::Mat
2. Perform denoise operation on the cv::Mat
3. Write the frame back onto the disk

Computational time taken for denoising may not be worth it in the end - will be a rather experimental feature.

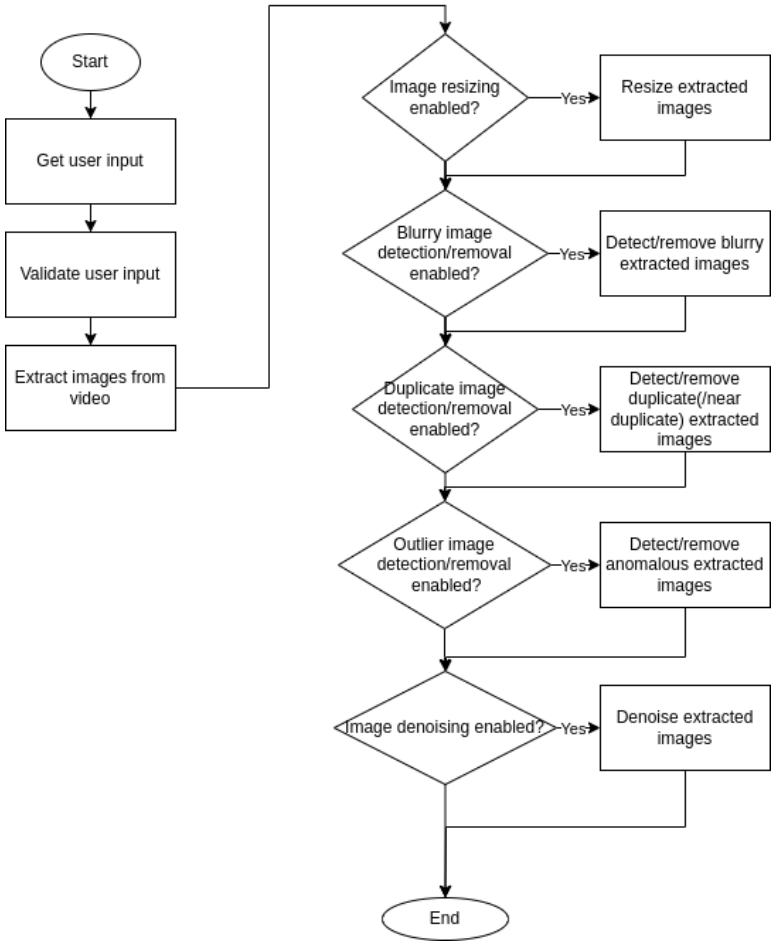
2.3 Algorithms

This section describes the algorithms the overall solution compromises of, how they work, and how the combine into a functional program. The algorithms described here may not be the optimal solution, and I will likely perform a pass of optimisation over the whole program once it meets all of the clients requirements. This optimisation pass will likely end up modifying exactly how some of the algorithms described here work.

2.3.1 Overall vid2photogrammetry algorithm

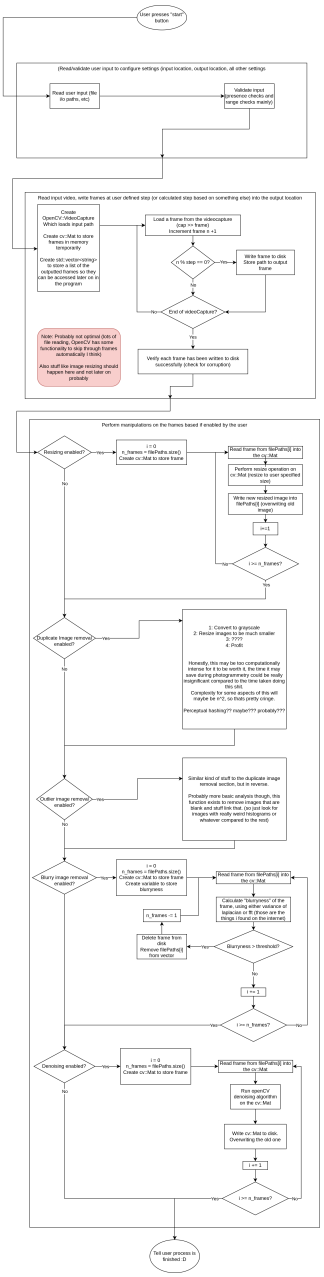
On a high level of abstraction, the vid2photogrammetry program is reasonably simple. The simplicity of the program comes from the fact it only performs a linear process; Input goes in, a few stages of processing happens, and then an output comes out. There are no complex simultaneous processes. Figure 2.4 gives an overview of how vid2photogrammetry will function, on a high level of abstraction.

Figure 2.4: Overall vid2photogrammetry algorithm



This algorithm gives an idea of what the program needs to do, but does not describe at all how to do it. Figure 2.5 provides a more detailed overview of how the program will operate, but still lacks detail which will be described later in the design document.

Figure 2.5: A more detailed vid2photogrammetry algorithm

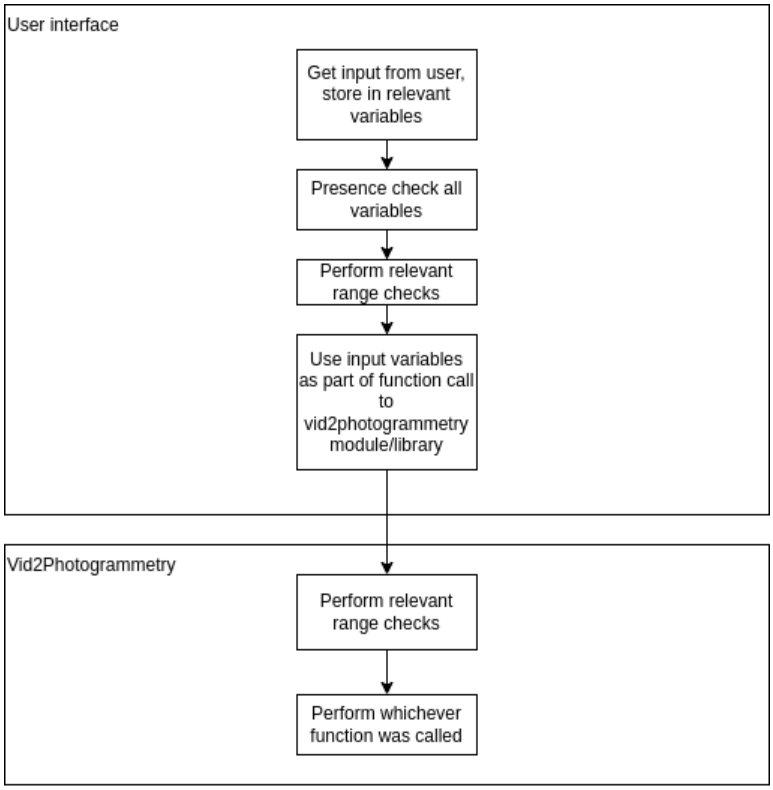


2.3.2 Individual algorithms

2.3.2.1 Fetching/validating input

Fetching user input will be handled by the interface program, but validation must also take place inside the vid2photogrammetry core library to minimise the potential of unexpected errors occurring.

Figure 2.6: Input validation



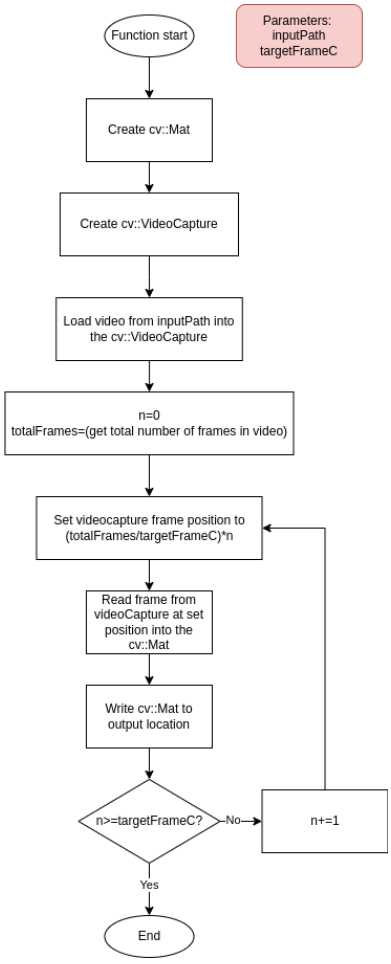
The exact details of which variables need to be validated, and how exactly they need to be validated has not been included in figure 2.6 (at least not yet), this is because the diagram is meant to give a general overview of how input will be checked. Input will be checked by the C++ vid2photogrammetry library, but including input validation inside the GUI (or command line interface) will make it easier to notify the user that their input is missing or malformed.

To validate filepaths, the following must be checked:

- The file or folder exists
- The program has read/write permission (write only required for output folder)
- output folder must be empty

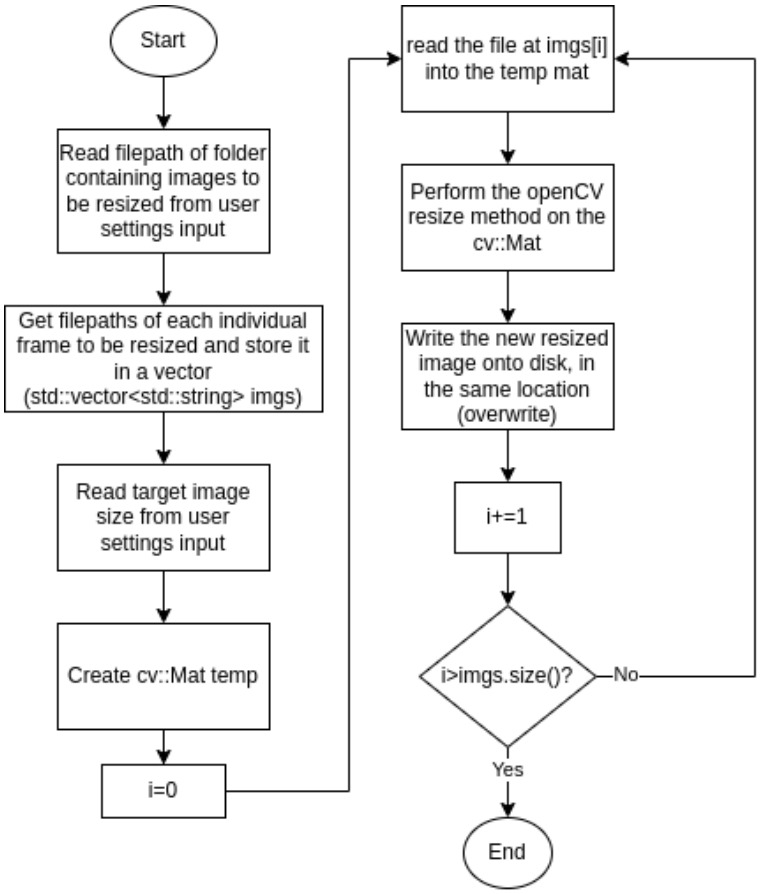
2.3.2.2 Extract images from video

Figure 2.7: Frame extraction to disk



2.3.2.3 Resize extracted images

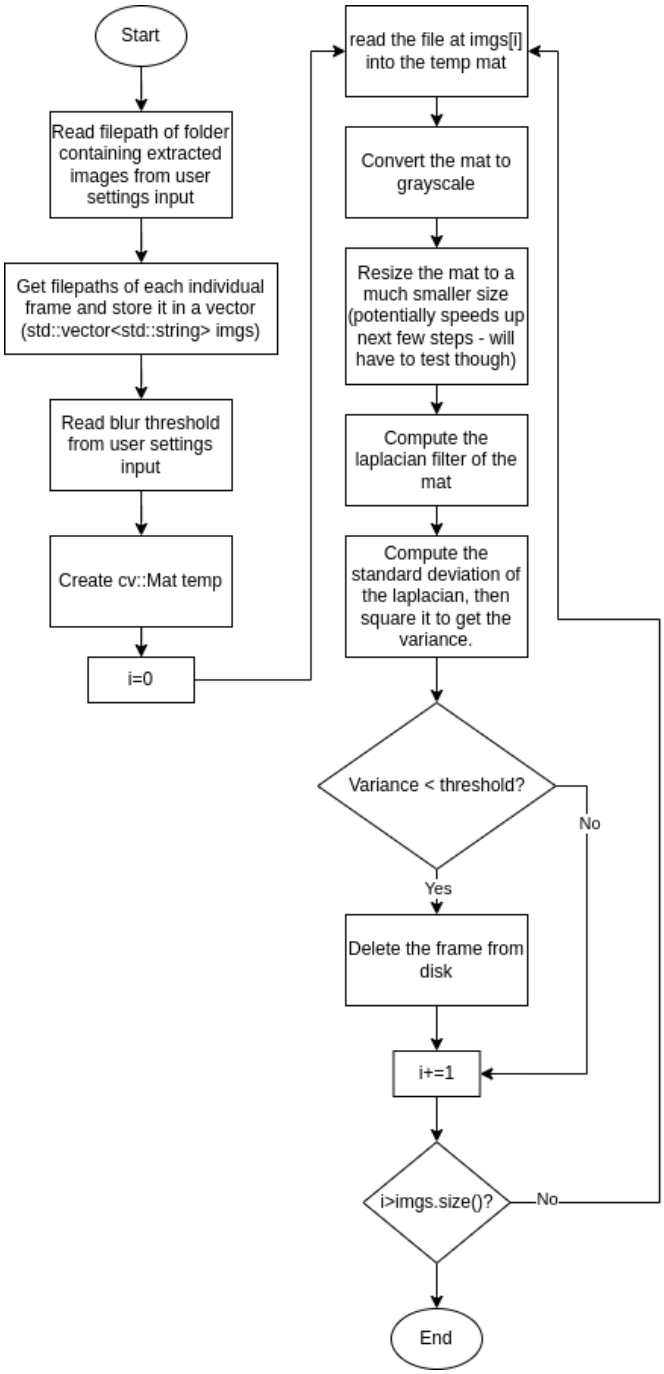
Figure 2.8: Resize extracted frames stored on disk



2.3.2.4 Detect/remove blurry images

The algorithm for quantifying image blurriness will have to be experimented with during development. Computing the "variance of the laplacian" appears like it could work pretty well based on my research, and shouldnt be too hard to implement using openCV.

Figure 2.9: Blurry frame detection



2.3.2.5 Detect/remove duplicate(/near duplicate) images

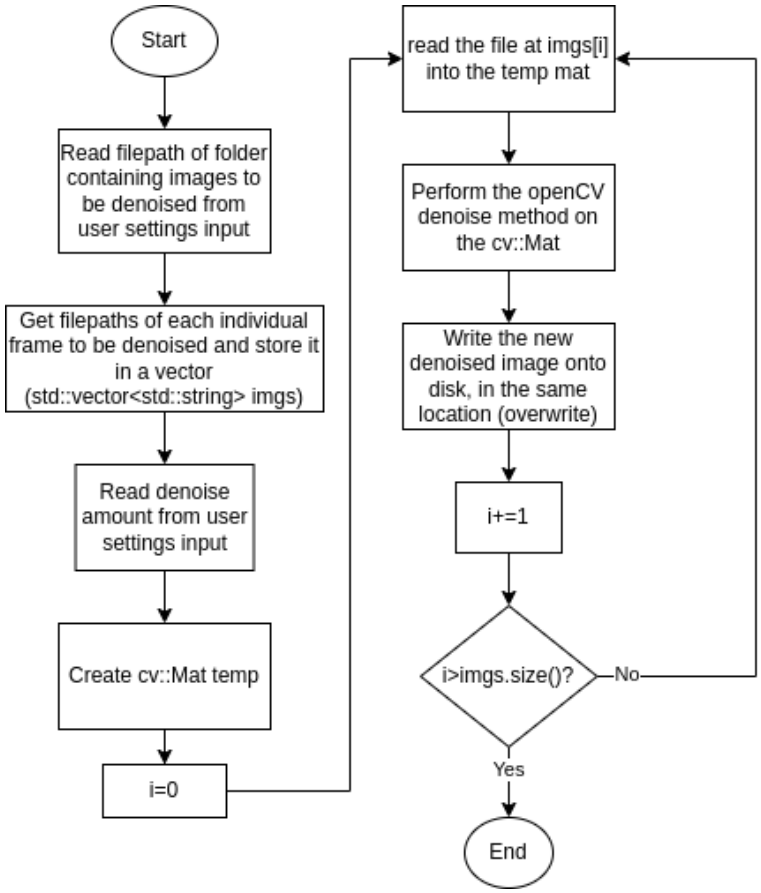
Something something resize the image really small and do something wacky. There are a couple ways i can think of doing this and they probably wont be easy.

2.3.2.6 Detect/remove outlier images

Just like above, wacky stuff required.

2.3.2.7 Denoise images

Figure 2.10: Denoise extracted frames stored on disk



2.3.3 How do they all combine?

2.4 Usability features

2.4.1 Graphical user interface

2.4.1.1 Minimum viable product

Make something basic first that does the bare minimum, then make a fancy looking one.

2.4.2 Scripting via python module

2.5 Key variables, structures, and classes

2.5.1 Key variables

Name	Type	Description	Validation
inputVideoPath	std::string	Stores the path to the input video (or image sequence) file(s)	Presence check, format check.
inputVideoCapture	cv::VideoCapture	An OpenCV video capture object used to load frames from a video stored on the disk	The .isOpened() method can be used to verify a video has been loaded.
loadedFrame	cv::Mat	Frames are loaded into this variable temporarily during the loading process	Must check every time a frame is loaded that it loaded properly (check loadedFrame is not NULL, presence check.).
2 First	Second	Third	Fourth

2.5.2 Structures

2.5.3 Classes

2.6 Test data

2.6.1 During development

During early development, almost any video will work to test basic functionality. But one feature of test data which will make my life a lot easier will be baking frame/timestamp metadata into each frame of a video. This will allow me to see exactly which frames are being extracted, which frames are being deleted, and all that kind of stuff. Figure 2.11 shows an example of this metadata being present in the actual frames of a video.

I can easily add this metadata by importing a video into blender, adjusting a couple settings, then exporting the new video.

As I get to work on the more specialised features, I will have to capture real photogrammetry data and then do some actual photogrammetry test runs with it.

Figure 2.11: Burnt metadata example (not photogrammetry capture data)

2.6.2 Post development

Post-development test data will not include debugging features such as burnt-in frame/timestamp metadata, and will focus much more on experimenting with how the program settings can be optimised to produce the best output. The goal of post-development testing will be to figure out how to record optimal video for photogrammetry, and how to optimise it even more by tweaking the vid2photogrammetry settings.

2.7 Optimisation