AN INTRODUCTION TO 3D RECONSTRUCTION using VisualSFM and PMVS2/CMVS

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1. Introduction

1.1. About VisualSFM

VisualSFM is a GUI application for 3D reconstruction using structure from motion (SFM). The reconstruction system integrates and improves upon several of my previous projects: A course project to implement a PhotoTourism-like incremental SFM system, SIFT on GPU(SiftGPU), and the recent Multicore Bundle Adjustment. VisualSFM is able to run very fast by exploiting multicore parallelism in feature detection, feature matching, and bundle adjustment. In addition, VisualSFM provides the interfaces to run Yasutaka Furukawa's PMVS/CMVS tool and to prepare data for Michal Jancosek's CMP-MVS. This software also comes with two research projects: Schematic Surface Reconstruction and Single View Repetition Analysis. (source: http://homes.cs.washington.edu/~ccwu/vsfm/).

1.2. About PMVS2/CMVS

PMVS is a multi-view stereo software that takes a set of images and camera parameters, then reconstructs 3D structure of an object or a scene visible in the images. Only rigid structure is reconstructed, in other words, the software automatically ignores non-rigid objects such as pedestrians in front of a building. The software outputs a set of oriented points instead of a polygonal (or a mesh) model, where both the 3D coordinate and the surface normal are estimated at each oriented point.

Many multi-view stereo (MVS) algorithms do not scale well to a large number of input images (lack of computational and memory resources). This software (CMVS) takes the output of a structure-frommotion (SfM) software as input, then decomposes the input images into a set of image clusters of managable size. An MVS software can be used to process each cluster independently and in parallel, where the union of reconstructions from all the clusters should not miss any details that can be otherwise obtained from the whole image set. CMVS should be used in conjunction with an SfM software Bundler and an MVS software PMVS2 (PMVS version 2).

Multi-view stereo software PMVS2, which is included in the CMVS package, was developped when Yasutaka Furukawa was a graduate student at University of Illinois at Urbana-Champaign under the supervision of Prof. Jean Ponce, who was affiliated with University of Illinois at Urbana-Champaign and Ecole Normale Supérieure. Further modifications and enhancements were added when Yasutaka Furukawa was a postdoc at University of Washington. (source: http://www.di.ens.fr/pmvs/).

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2. Installations

2.1. VisualSFM

- Goto http://homes.cs.washington.edu/~ccwu/vsfm/
- Current version is 0.5.21
- Choose your operating system

```
homes.cs.washington.edu/~ccwu/vsfm/

I Add Seaffe images 2 Match the images 4 Dense Reconstruction

and, you still have the option to run from command line without a GUI!

VisualSFH sfm+pmvs ./images ./result.nvm

Download V0.5.21 (Many UI improvements, More options, Poisson, ... changelog)

Windows (x64, win32, install instructions, pba.dll for non-nVidia system)

Linux (x86_64, i386, install instructions)

Mac OSX (x86_64, i386, install instructions, check out the package contributed by Iván)

* Post questions and see discussions at our Google Group, or email me with VisualSFM in

* VisualSFM is free for personal, non-profit or academic use. Check README for more det
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Figure 1 Downloaing VisualSFM.

• Unzip to your desired directory

2.2. PMVS2/CMVS

• Goto https://github.com/TheFrenchLeaf/CMVS-PMVS/

github Explore G	itHub Se	earch Fe	atures Blog				Sign up	for fre	e Si	ch with gn in
TheFrenchLeaf /	CMVS-PI	MVS				*	Star	31	₽ Fork	12
Code		Network	Pull	Requests 0	Issues	2		G	raphs	
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Figure 2 Downloaing PMVS2/CMVS.

• Press 'ZIP' button to compress and download the software.

- Open the compressed file, copy the following files to your VisualSFM's directory.
 - cmvs.exe
 - genOption.exes
 - pmvs2.exe
 - pthread.dll

3. Data Preparations

3.1. Create a working directory, i.e. C:\uavdata, we will call this directory as ROOT.

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🔆 Favorites	Name	Date modified	Туре	Si
📃 Desktop	AppServ	7/1/2556 0:54	File folder	
🚺 Downloads	MSOCache	31/1/2556 5:28	File folder	
🔛 Recent Places	JE NVIDIA	7/1/2556 15:43	File folder	
	퉬 PerfLogs	14/7/2552 10:20	File folder	
词 Libraries	퉳 Program Files	15/1/2556 21:59	File folder	
Documents	퉬 Program Files (x86)	7/2/2556 2:44	File folder	
👌 Music	ProgramData	31/1/2556 5:29	File folder	
E Pictures	🎉 uavdata	10/2/2556 3:16	File folder	
💾 Videos	🎳 Users	6/1/2556 23:16	File folder	
	🎍 Windows	31/1/2556 5:29	File folder	

Figure 3 Creating working directory.

- Put all of your images inside the ROOT directory.
- All images should be saved in JPEG format.
- For testing, you may resize the images to smaller dimensions, i.e. 800x600. This may decrease the number of correspondences; but it will run much more faster than using the full resolutions.

4. Sparse Reconstruction

• Start the application software by double clicking at VisualSFM_win32.exe icon.

 IMPORTANT: By default, the software will run its feature detection and matching algorithms in parallale using the multi-threading technique. However, this may crashs in some machine. Therefore, you may need to disable this option by going to SfM->Pairwise Matching and uncheck the Multi-threaded Match option.

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٦	Two-View Match Pairwise Matching	•	■ 四 照 100 - 1 0 0 - 1 0 0 0 0 0 0 0 0 0 0 0 0	
	Reconstruct 3D Resume SFM Run CMVS/PMVS More Functions	,	Compute Specified Match Compute Sequence Match Compute Missing F-Matrix Update Pairwise F-Matrix	
	Load NV Match ADD NV Match Save NV Match		Use Prioritized Subset Image: Multi-threaded Match Asynchronous Write	
	Clear Workspace Extra Functions	•	Import Feature Matches Export Feature Matches	
	Delete Camera Delete One Model Delete All Models		Show Spanning Forest Show Match Matrix	

Figure 4 VisualSFM's mult-theading option.

Import your images into VisualSFM by selecting File -> Open + Multi Images, or clicking on at the toolbar.

File SfM View Rep Sw	p To	ols	He	lp										
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Open+ Image & SIFT Open Current Path														
Detect Features Load Feature File														
New <u>W</u> indow <u>C</u> lose Window														
Exit Program														



• You can select multiple images by holding SHIFT or CTRL key while clicking on the images.

• The program will then loads and shows some image information in the Task Viewer window.



Figure 6 Viewing image thumbnails.

• In the Task Viewer, you should see the following information:

80: IMG_6969	
image_size:	800x600
focal_length:	2775.268
#sift count:	7334

• Run SIFT feature detector and matcher. Select SFM->Pairwise Matching->Compute Missing Match to run the detector and matcher.



Figure 7 Compute missing matches.

• Wait until the algorithm finishs its task. The Task Viewer should look like this.

Task Viewer	8
Task Viewer 10076 and 0078: E[41/66], H[7], 0.04sec 10076 and 0079: E[20/42], H[6], 0.06sec 10076 and 0097: E[20/42], H[6], 0.02sec 10076 and 0083: E[345/474], H[63], 0.02sec 10076 and 0083: E[345/474], H[63], 0.02sec 10077 and 0079: F[107/235], H[65], 0.01sec 10077 and 0079: F[107/235], H[63], 0.02sec 10077 and 0081: E[330/379], H[78], 0.02sec 10077 and 0081: E[53/90], H[63], 0.03sec 10077 and 0081: E[53/91], H[63], 0.03sec 10078 and 0081: E[53/201], H[63], 0.04sec 10078 and 0081: E[53/201], H[63], 0.04sec 10078 and 0081: E[142/158], H[53], 0.04sec 10078 and 0081: E[142/158], H[63], 0.04sec 10078 and 0081: E[163/241], H[63], 0.03sec 10079 and 0081: E[163/241], H[74], 0.03sec 1079 and 0081: E[163/241], H[75], 0.03sec 1079 and 0081], H[71/24], 0.03sec 1079 and 0081], H[71/24], 0.03sec 1079 and 0081], H[71/24], 0.03sec 1079 and 0081], H[71/	
0080 and 0031: E[497/653], H[107], 0.02sec 0080 and 0083: E[3/62], H[10], 0.03sec 0080 and 0083: E[3/72], H[13], 0.02sec 0081 and 0083: E[5/77], H[13], 0.01sec 0081 and 0084: E[7/7], H[13], 0.01sec 0082 and 0084: E[672]/60], H[72], 0.02sec 0082 and 0084: E[672]/60], H[72], 0.03sec 0083 and 0084: E[621/662], H[40], 0.03sec ####################################	
Compute Missing Pairwise Matching, finished Totally 39.767 minutes used	

Figure 8 Results of feature matching.

• Next, run Sparse Reconstruction. Select SFM->Reconstruct 3D or clicking on at the application toolbar.



Figure 9 Reconstruct sparse 3D point.

• Wait until the reconstruction is completed.

• You should see something like this.



Figure 10 Sparse pointcloud.

- Mouse Controls and Navigation:
 - **Right double click** on a camera in 3D point mode to view the selected image
 - Left double click on an image in thumbnail mode to view the selected image
 - **Right double click** in the single image mode to return to previous view mode.
 - Pan/rotate by Left/Right click + hold + move.
 - Zooming by Shift + Mouse, or mouse wheel
 - change point size by using Alt + Mousewheel
 - Change the relative camera size by Ctrl + mouse wheel.
 - Just try left/right double/single clicking (on empty space or on camera, on image)
- You may now save the reconstructed data. Select SFM -> Save NV Match and give your desired NVM filename. Please note that the NVM must be saved in the same directory as the image files.
- You can add more images, compute the missing matches and run the sprase reconstruction again.

5. Dense reconstruction using PMVS2/CMVS

• Run dense reconstruction by selecting the menu: SFM -> Run CMVS/PMVS. You will be ask to save the NVM file. Please note that the NVM file must be saved inside the same directory as the image files.



Figure 11 Runing Dense reconstruction.

- The CMVS will analyze your sparse results and create multiple clusters and input files for feeding into PMVS2. After that, PMVS2 will run dense reconstruction cluster-by-cluster.
- IMPORTANT: the dense reconstruction processes are both resource and time consuming and they may take all of you machine resources, i.e. 100% of both RAM and CPU cores. Therefore, please be patient!.
- For each cluster, the number of reconstructed 3D points will be shown in the Task Viewer. If the number of vertices is reported as 0, then the dense reconstruction is failed. When PMVS2 finishs its jobs, the dense pointcloud will be saved in the PLY format. It will have the same filename as you have entered, but the file extension will be xxxx.0.ply.
- View the dense pointcloud by selecting the menu: View->Dense 3D Points.



Figure 12 Dense pointcloud.

6. Save/Export

- Select the menu: SFM -> Save NV Match
- Select your target file type in the Save in type dropdown menu.



Figure 13 Exporting data.