In the past several years, there have been some interesting developments and availability of open source software that allows people to create point clouds and models based on using nothing more than their digital cameras and free software available online. The development has been rather rapid and the options of using different packages has been growing with more research and individual programmers donating their time to provide solutions to the creation of 3D point clouds and meshes that can be directly imported into CAD or modeling packages. Not many people in the Forensics area have considered what open source can do for them nor might they be aware of the capabilities of using open source tools.

This multi-part article will present several open source solutions to creating point clouds and 3D models for use in Forensic applications and will look at some of the pros and cons of each.

When we think about 3D documentation and creating models for use in a forensic reconstruction, we often think about the high tech instruments that are used to document crime and accident scenes. Things like laser scanners, structured light scanners, total stations and even photogrammetry packages for creating dense point clouds or meshes. Many of these technologies are rather expensive and/or require a significant investment in time to learn and convert the captured data into a useable 3D model. For every law enforcement agency that owns a laser scanner, there are many more that just do not have the funding to consider such an expensive piece of equipment. Smaller agencies are often underfunded and have to look at being resourceful to get what they need. In these situations, open source tools can provide some excellent resources.

Other than hobbyists, many people who work in Forensic Visualization do not often consider the open source route. This could be due to the fact that “free” often suggests that there is a “catch” or that something is inherently lacking in the overall product quality or in features and therefore, there can be a negative connotation with open source tools. In truth, there are always limitations to open source software (and in many cases paid software too) but this often depends on what you are attempting to do. Most importantly, if we understand what the limitations are and focus in on the strengths of these open source 3D tools, we can often develop useful and visually impressive 3D content for use in analysis or visualizations.

Microsoft - Photosynth
If you haven’t heard about Microsoft’s Photosynth, you might want to check out this neat little application that is provided for free. Originally created at the University of Washington and then further developed by Microsoft, Photosynth has been around now for a several years and is a very simple way of organizing your photos of a particular object or environment such that the photos are spatially oriented with respect to one another. Unlike panoramic images, where you can stitch a number of photographs together to create a 360° image of a scene, Photosynth is a combination of technologies
that solve for the common features between photos and how each of the photos are oriented with respect to one another in 3D space. As the images are matched, the camera positions are calculated and features in each photograph are matched to create 3D points. These "points" define accurate features in a virtual space that are common between photos and by taking enough photographs of an object, it is possible to construct a point cloud from the "synthed" images. In effect, this makes it one of the only free "3D scanners" that can be utilized to get relative distances between point features of an object.

The Photosynth Process
The first thing required is to visit the Photosynth website and to create an account. This will allow the user to download and install the local Photosynth application on their computer that ties into the Photosynth server which actually processes the data. A user account allows up to 20Gb of data to be uploaded (which is usually plenty). At this point, the user simply needs to launch the Photosynth application on their local PC and then proceed to "Add Photos" from their local drive.

Users have the option to make their "synths" either Public or Unlisted. However, it is important to note that although Unlisted "synths" are not able to be searched or made available to others, if the direct link is made available, anyone who has access to the link has access to view the Photosynth and all the photos that were uploaded.

Of course, there is a whole larger issue for crime scenes where there is sensitive information contained in the photographs. This is a rather large issue to overcome and it is not recommended to upload any sensitive photographs to a public server. However, for general modeling and capture of non-sensitive information, this could be perfectly acceptable.
Once all the photos are selected and the Name, Tags and Description section has been filled out, the user simply needs to press the Synth button and the software begins to process and upload the data to the Photosynth Server.

![Create Synth](image)

**Figure 2 -** Screen capture of the Photosynth application where photos have been selected and all titles and descriptions have been filled in.

Depending on the number of photographs and internet connection speed, this process can take anywhere from a few minutes (a dozen photos) to a few hours (for hundreds of photos). However, in terms of actual processing time from the user, this is it! Once complete, the user can view their Photosynth by signing into their account and going to "My Photosynths".

![Rusted Red Car](image)

**Figure 3 -** Part of a screen capture for a Photosynth of a **Rusted Red Car**.
Manipulation is rather simple in that you can simply click on the synth and small windows showing oriented photographs will become available where you can click and automatically be presented with another view. If you want to see the point cloud, simply click the "p" key and it will cycle through showing the photos and matched 3D points. Alternatively, the icon allows you to switch to one of four different types of views.

![Figure 4 - The Rusted Red Car synth showing the matched 3D feature points.](image)

**Exporting the Photosynth Points**

Having all this information processed and up on the Photosynth website is great, but in order for it to be useful, users need to be able to get access to the point cloud data. Although Microsoft has not provided a solution to this, they have left room for developers to gain access to some of the point cloud information. Originally, this was a very tricky process and was not user friendly. However, there is now a small application available called SynthExport, written by Christoph Hausner and made available on the CodePlex website. This little application is extremely user friendly and all that is needed is that the user enter in the URL of the Photosynth and the application automatically writes out the point data in a number of formats including PLY, OBJ, VRML and X3D. These formats can then be directly imported into any number of 3D Modeling or Point Cloud editing software packages for further work.

Note: If you happen to be on a budget, try exporting points from SynthExport in PLY format and then import into MeshLab (free open source 3D application).
Figure 5 - The SynthExport application that allows users to export the point data from their Photosynths.

Figure 6 - Photosynth feature matched point imported into MeshLab

Other Considerations

Although Photosynth was originally intended as a creative means of presenting photographs for virtual tours, what makes it technically appealing is that it can solve for the relative spatial relationships between photographs and camera distortions without knowing anything about the camera that took the photograph, and it does it relatively quickly.

The impact of this type of technology is that first responders, forensic technicians and investigators can quickly gather a large number of photographs without the need for special targets, expensive equipment or complicated software. The user just needs to take a lot of photos that cover the object all around and close up (either by physically moving closer to the object or by using a zoom lens). Once the photos are captured, they can be easily processed in Photosynth by a user with little to no training. There are actually very few steps involved in creating a "synth".
However, this simplistic approach is one of the areas where further development has been needed since there is little control over the resulting point cloud, the points are in a relative coordinate system with no scale and there are no integrated filtering, editing or measuring tools. The resultant 3D points are a by-product of the feature matching technology and currently, the only way to control the density of the point cloud is really to take a lot of photos for the software to process. Any post analysis of the point cloud requires the use of third party software for viewing and cleaning of stray points and "noise". (Another possible area of development).

Fortunately, there are other tools available written by programmers that can access features of the Photosynth and that can produce dense point clouds...(a topic for a follow-on article). Two tools that can be used are the Photosynth Tookit (currently at version 7) and the SFM (Structure From Motion) Tookit.

As stated previously, one major issue with the structure of Photosynth is that users currently download one part of the software application to their local hard drive, but the photos must be uploaded to a server for viewing on the Photosynth "network". As a result, the default settings make all the "synthed" photos available publicly. There is an option for creating an unlisted "synth", but it does not provide secure encrypted access. Anyone who has access to the URL for the "synth", can get to it. Therefore, security for sensitive investigations is a major issue.

Like many other technologies, Photosynth needs to run its course through much validation and testing. One feature lacking is a quality indicator of accuracy or error. Currently, there is a measure that refers to how "synthy" the processed photos are measured in percent (%). Unfortunately, this is really not useful indicator of accuracy, but it would seem that this could be overcome with some added analytical tools. Of course, the most simple solution here is for the user to take some reference measurements of the object they are photographing so that they can use this data for subsequent validation and accuracy.

Photosynth is still a long way from becoming a main tool for forensic investigators, but it would seem that this technology has some benefits for creating 3D assets in a forensic environment. There needs to be specific tools included and certain security measures addressed, but considering how many times a day digital cameras are used to capture and record data at accident and crime scenes, the impact of a product like Photosynth, could be immense.

For more information about Photosynth, visit http://photosynth.net/

The Photosynth Photography Guide

Additional links to interesting Photosynths:
http://photosynth.net/view.aspx?cid=e5b84afd-6f88-40f9-a023-a7461eb883b
http://photosynth.net/view.aspx?cid=f632c827-7107-4759-9727-1f209701ab2e
In the past several years, there have been some interesting developments and availability of open source software that allows people to create point clouds and models based on using nothing more than their digital cameras and free software available online. The development has been rather rapid and the options of using different packages has been growing with more research and individual programmers donating their time to provide solutions to the creation of 3D point clouds and meshes that can be directly imported into CAD or modeling packages. Not many people in the Forensics area have considered what open source can do for them nor might they be aware of the capabilities of using open source tools.

This article is the second instalment in a series of 4 articles that will present several open source solutions to creating point clouds and 3D models for use in Forensic applications and will look at some of the pros and cons of each.

Photogrammetry has historically been associated with aerial surveying with an emphasis on photo interpretation and mapping so that some information about a foreign country could be known for security purposes or so that land masses could be documented and mapped. Generally speaking, the information extracted from photographs for many years was limited to point and line information (such as contours and elevation). However, since the advances of computer hardware, software and new mathematical models, the amount of data that can be extracted from a series of images has increased enormously and is no longer limited to simple points and lines. Dense point cloud reconstructions and even meshed models are now available in open source format.

Today, many off the shelf software packages such as PhotoModeler Scanner and Elcovision 10 have the ability to automatically orient a series of images taken from a wide range of angles (either terrestrial or aerial) and allow greater flexibility and ease of use in extracting 3D information from photographs. These software packages use matched feature points in the images to generate 3D point data and with enough features matched in a set of photos, there exists the possibility of creating fully textured and meshed 3D models.

Autodesk Labs- Photofly
In a previous article, I had a look at Microsoft's Photosynth that was initially developed for virtual tours. Photosynth has evolved into a very popular product capable of providing dense point clouds of imaged objects, but it lacks some of the additional tools and flexibility to refine the resultant matched 3D points. In a similar fashion Autodesk's Project Photofly 2.1 has similar capability except that it produces a fully textured 3D model based on the images and not just a point cloud. Photofly uses a very similar workflow to Photosynth in that the user can simply take a series of photos with a camera of an object and then by uploading the photos, the software will automatically orient, feature match and create a
fully textured 3D model. This model is then emailed as a file or link for download. Once downloaded, Autodesk’s Photo Scene Editor is used to view and edit the mode.

Considerations for Use
Perhaps the most important point to remember is that Project Photofly is still in beta and is not meant as a tested and validated piece of software. There are no quality indicators except the user’s own subjective interpretation as to how well the resultant 3D mesh matches the real object. Therefore, validation and testing is required to show that Project Photofly can eventually be used as a primary Forensics tool. However, if we consider how relatively simple it is to create 3D assets of secondary objects that provide more realism in 3D Reconstructions of crime scenes, then it can be perfectly suitable.

As previously noted in the Photosynth article (Part 1), there are security considerations to take into account. Unlike Microsoft’s Photosynth, Autodesk does not make any of the photos readily available on a public server; however the mere fact that photos need to be uploaded to an uncontrolled server outside the domain of the user’s control means that photos are at risk of exposure. This is simply not acceptable and anyone attempting to create models of active cases with sensitive photographs is putting themselves at risk!

Features
Some of the major features of Photo Scene Editor worth noting up front are that users have options to:
1. Create a reference scale whereby the entire 3D model is scaled accordingly.
2. Take reference measurements once scaled
3. Refine and edit the mesh resolution and delete unwanted parts.
4. Export the 3D model in formats compatible with most 3D programs.
5. Export the data as a point cloud.
6. Animate the 3D model directly in the software and subsequently export the animation.

The Photofly Process
In order to get started, the user needs to go to the Photofly website, read the Terms of Use and then download and install the "PhotoSceneEdito2.1.msi" file. Although the technology is still in beta, some of my own results have been rather impressive with little time to get up and going. In the image below of a quad bike, approximately 50 photographs were uploaded to the Photofly cloud servers and the "photo scene" was returned by email for subsequent editing in the "Photo Scene Editor" software (which by now is already downloaded and locally installed on the user's computer).
In order to compute a 3D scene the user needs to head out and take photos of an object or environment. The photographic component of this process should not be underestimated because it can make the whole difference between a great model and one that looks like an utter mess. Blurred photographs, out of focus objects and poor overlap between photos will all cause major problems in the end result. It’s important to fill the view of the camera with the object of interest. Also, use the "ring method" to surround the object with the camera moving in small increments. In the end you could easily end up with 40 or more photos of an object. Further information is available, see the "Autodesk Labs Project Photofly 2.0 Shooting Guidelines" here.

Once the user launches Photo Scene Editor (Note: Don’t look for Photofly on your hard drive it is in fact called "Autodesk Photo Scene Editor"), a very simple user interface will appear and will look similar to the image below:

![Image of Photo Scene Editor]

The start-up screen gives the user the option to create a new scene, open and existing scene, choose recently opened files or watch some video tutorials. Simply click on "Create a new Photo Scene" and
another window will appear where you can select the location of the images to be used for model creation. Of course, it’s best to have all your photos in a separate folder so they can be easily selected, although once you select the first set of photos, you do have the option of adding additional photos from other directories.

![Figure 3. Browser window to select photographs.](image)

Once the desired photos are chosen, simply click on "Compute Photo Scene". Once again, another window will appear where you enter your email address and the name of the "scene" and then choose to either wait or receive an email when the entire set of images has been processed.

![Figure 4. Photo Scene Editor window prior to commencement of computation.](image)
Figure 5. Name the Photo Scene and enter an email address where the file should be sent.

At this point it's a matter of waiting. In my own tests, computation varied between a few minutes to an hour with 100 photos or more (resolution dependant of course). All the photos need to be uploaded first and then subsequently, computations are made to orient and solve for the 3D reconstruction. When ready, you will receive an email link to a file with the “3dp” extension. This will automatically open the Photo Scene Editor software where you can work on your project.

When first opening a new 3dp project file, it will usually arrive at a low resolution, fortunately, there is an option to choose a medium or high quality mesh that will require subsequent processing and wait time, but I have found this to be only a few minutes in most cases. Increasing the mesh density can often give better results if the photos set has been properly acquired.

Figure 6. Initial view of the Photo Scene Editor window with 3dp file opened.

In the image above, it can be seen that not all photos were able to be oriented in the processing, these are indicated with the small yellow warning sign with an exclamation.
In the event that some photos have not been added to the project for whatever reason, there is a manual stitching feature that allows the user to select and reference points in multiple photographs. This stitching is really only necessary when the mesh is poorly formed or there are clearly areas missing. To access this feature, simply double click on any of thumbnails with the exclamation mark and the Manual Stitch window will appear.

At this point the image on the left (as shown in Figure 8) is our reference image and we can change the images on the right so that common feature points are shown. Clicking over an image gives you a magnifier window where you can zoom into your photograph (use thumbwheel). Once a point is selected, move to the next photograph and select the same point. Once 4 points are matched, a window appears indicating that enough information has been provided to orient the previously unoriented photograph.
One important feature of any new project file is that it has no scale. However, Autodesk Labs has conveniently placed a scale tool so that reference points can be selected and then a scale applied. This is not as intuitive as one might imagine though because you need to create a set of points in the model before they can be assigned a scale. Therefore, directly selecting the mesh and trying to apply a scale will not work. First, select a photograph with a particular view you are interested in from the images in the bottom row. Remember that these need to be oriented photographs and not any of the ones indicating a warning. The "Create Reference Point" icon will become active and will allow you to click anywhere on the mesh to create a point. Do this for any two points that will define a scale and you can then click on the "Define Reference Distance" icon, select the two previously created reference points and then enter the scale. The entire model will then be subsequently scaled accordingly.

Additional features such as distance measurement, defining world coordinate systems and exporting a video of the model are all possible, but the most important feature is to be able to export the model to other 3D packages. Exporting is done by going to File -> Export Scene As where you will be presented with a number of options:
Figure 10. File menu showing the export menu item.

Figure 11. Selectable options for export

Figure 12. Screen capture in 3ds Max showing the imported fbx model with textures.

It will be interesting to watch and see how Photofly progresses and develops in the near future. There is still some "hit and miss" when creating a 3D model simply because there are many factors that influence the feature matching in a photogrammetry based package.

Currently, there is no firm date or timing when Autodesk might finally pull the plug on Project Photofly's beta status, but this could certainly be a useful tool for creating 3D environments and 3D assets for crime scene reconstructions.

Below are some interesting links to Photofly animations:
http://labs.autodesk.com/technologies/photofly/gallery/
http://www.youtube.com/watch?v=2YaKjIsIdSs&feature=related
http://www.youtube.com/watch?v=O6Qqe2YUL-g&feature=related
http://www.youtube.com/watch?v=9dW9d65Unrs&feature=related
In the past several years, there have been some interesting developments and availability of open source software that allows people to create point clouds and models based on using nothing more than their digital cameras and free software available online. The development has been rather rapid and the options of using different packages has been growing with more research and individual programmers donating their time to provide solutions to the creation of 3D point clouds and meshes that can be directly imported into CAD or modeling packages. Not many people in the Forensics area have considered what open source can do for them nor might they be aware of the capabilities of using open source tools.

This article is the third instalment in a series of 4 articles that will present several open source solutions to creating point clouds and 3D models for use in Forensic applications and will look at some of the pros and cons of each.

In my two previous articles I provided two different methods of producing a point cloud using Microsoft’s Photosynth and also a 3D meshed models using Autodesk’s Photofly. Both of these products are based on the user having to upload a set of images to a server for processing and unfortunately, from a Forensics and Security standpoint, this is a major issue. Since photos cannot be controlled once they are uploaded to a private company’s server.

However, there is another option available called VisualSFM that allows you to keep all the photos on your own PC and it has the ability to process dozens of photos to create a very dense set of point clouds.

Visual SFM
The basic concept of VisualSFM (Structure From Motion) began in 2006 and was led by Changchang Wu, a student at the University of North Carolina at Chapel Hill, while trying to find a project idea for a "3D Urban Modeling" seminar. After graduating, Changchang Wu joined the University of Washington GRAIL lab where "Photo-Tourism" (the predecessor to Microsoft’s Photosynth) was born.

What makes VisualSFM interesting is right in the name, it’s "visual"! This application has a graphical user interface and although it is still being improved with features and options, it has excellent capability to rapidly process hundreds of photos by taking advantage of the computer’s nVidia or ATI graphical processing unit (GPU).

Installation of the base package requires a few steps. You first need to ensure that you have an ATI or nVidia video card and then download VisualSFM here. (Note that I have an nVidia card on my system and have not verified this for ATI cards). The downloaded file is a compressed file called VisualSFM_windows_64bit.zip. Simply extract the file and a folder will appear with all the contents for
the main part of VisualSFM. Also, VisualSFM is a self-running executable file and requires no installation; you simply double click on the executable file from the extracted folder. However, if you would like to create dense point clouds, then you will also need to install the code, PMVS/CMVS from here. PMVS/CMVS is what actually does the dense matching and point cloud generation on the large set of images. Ensure that you place these files in the same folder where the VisualSFM.exe file is contained.

Lastly, in the case that you have an nVidia card, you should also download and install the CUDA Toolkit directly from the nVidia website here. Be sure to choose either the 32 bit or 64 bit version for your version of Windows. The CUDA Toolkit comes with some files that allow you properly run VisualSFM. It’s an extra step, but not so difficult. Just be sure to choose the “Complete” installation (not “Typical” or “Custom”).

When launching Visual SFM, an empty main window will appear and look something like Figure 1 below. There is a “Task Viewer” to the right of the main application window that is often useful in watching the progress of the different processes (although you have the option to close the Task Viewer from the Tools menu).

![Figure 1. Interface for VisualSFM when first opened.](image)

The first step of the dense point cloud reconstruction process is to load the desired photos using the highlighted icon shown in Figure 2, below. The software allows you to load dozens or hundreds of photos. In my testing, I completed a photo set of over 500 photos! Select all the desired photos and click "Open".

![Figure 2. Open Multiple Images Icon](image)
VisualSFM automatically loads some information of the photos and this process is normally quite rapid based on the number of photos. When completed loading you will indeed get a message in the Task Viewer saying that it is done.

The second step is to now perform the feature matching between the images. This is done by pressing the icon with 4 opposed arrows shown in Figure 5. The results will immediately begin to show in the Task Viewer and a comparison of all the photos is done looking for similar features. This process uses the GPU and is relatively quick when compared to other non-GPU based feature extraction processes.
Once complete, the third step is to compute the sparse reconstruction. What happens here is that the relevant image matches between photos are now going to be calculated for their 3D positions in a relative coordinate system. This process is a precursor to the dense reconstruction, but is normally very quick. Figure 6 shows the highlighted icon and Figure 7 shows a sparse reconstruction for a set of images that were loaded for a portion of tire tread. The general form of the reconstruction is starting to take place and one can view the calculated points, camera positions and image planes in 3D. This can be manipulated using the left mouse button for pan, right mouse button for rotate and scroll wheel for zoom.
The fourth main step in the process is the actual dense reconstruction itself. Simply press the CMVS icon as shown in Figure 8, below and there will be a browser window that appears asking you what to name the created point cloud and a location for where to place the data. Once the file name is chosen, Task Viewer will then begin to show the relative process of dense reconstruction. The time to complete the dense reconstruction could be anywhere from several seconds for only a few images to several hours for larger data sets.

Figure 8. The CMVS icon runs the dense reconstruction.

Figure 9. Choose a new directory to place the created models.

Figure 10. Dense reconstruction of tire treads.
Once complete you should have a densely reconstructed point cloud show up in the main window of Visual SFM. Also, there will be a folder created where you chose to save the file and this will have a “models” folder inside the main directory where all automatically created dense reconstructions will be placed in "ply" format. This file is what can be opened in MeshLab for further processing.

![Figure 11. Folder location showing a generated model with initial name of 0000.](image)

Note that VisualSFM tries to match all the photos, but depending on how the photos were taken, any areas that are not able to be matched may cause a fragmented set of models and multiple models of dense reconstructions may be created in folders with sequential naming of 01, 02, 03...etc.

![Figure 12. Generated ply file in MeshLab](image)
There are several more options with VisualSFM that can be useful like tapping into the settings file and making adjustments to the dense reconstruction so that more points are matched. You can even manually assist the matching of photos when the application has problems finding a relationship between photos sets. Additionally, it is often useful to export a high resolution image of the current view using the "save current view" icon.

For further information on usage and help documentation, please visit the following link, http://www.cs.washington.edu/homes/ccwu/vsfm/doc.html#usage.
In the past several years, there have been some interesting developments and availability of open source software that allows people to create point clouds and models based on using nothing more than their digital cameras and free software available online. The development has been rather rapid and the options of using different packages has been growing with more research and individual programmers donating their time to provide solutions to the creation of 3D point clouds and meshes that can be directly imported into CAD or modeling packages. Not many people in the Forensics area have considered what open source can do for them nor might they be aware of the capabilities of using open source tools.

This article is the fourth instalment in a series of 4 articles that will present several open source solutions to creating point clouds and 3D models for use in Forensic applications and will look at some of the pros and cons of each.

In my three previous articles I provided information on different software that can create point clouds or meshes by capturing photos of an object or scene. In this last instalment, I will discuss another open source option that is perhaps the most popular among 3D enthusiasts. MeshLab has come a long way from the days of being a small lab project and today, there are many researchers and 3D enthusiasts who use it for point cloud manipulation, meshing and analysis.

MeshLab
Perhaps the most popular 3D point cloud and meshing software available as open source, MeshLab has really come a long way with respect to its features. MeshLab began in Italy at the University of Pisa in late 2005. It is an open-source general-purpose system aimed at the processing of the typical not-so-small unstructured 3D models that arise in the 3D scanning pipeline. MeshLab is oriented to the management and processing of unstructured large meshes and provides a set of tools for editing, cleaning, healing, inspecting, rendering and converting these kinds of meshes.1

MeshLab is available for Windows, MacOSX, and Linux. So, in order to get started, simply download the latest version of MeshLab from here. You can also download some sample files from the Stanford 3D Scanning Repository.

Words of caution to those who do not like to read instructions or prefer to jump right into the software and learn on the go. I would highly recommend that you look at some tutorials on YouTube or on the MeshLab website and save yourself a lot of heartache. MeshLab is quite powerful, but it takes some time to get to know many of the features and where to find many of the specific functions. In addition, there is a specific working procedure and method that you need to understand before jumping in head

1 http://en.wikipedia.org/wiki/MeshLab
first. Sometimes it takes some tweaking to get the settings just right and other times, the software can be buggy. However, you can often be surprised by what you can produce with MeshLab. When you first load up MeshLab you are presented with an interface that is rather clean and simple. In order to import a file, you need to either import an existing MeshLab project or use the "Import Mesh" command. This gives you a very large list of possible formats to import, however, the default format for MeshLab is the PLY file format.

PLY is a computer file format known as the Polygon File Format or the Stanford Triangle Format. The format was principally designed to store three dimensional data from 3D scanners. It supports a relatively simple description of a single object as a list of nominally flat polygons. A variety of properties can be stored including: color and transparency, surface normals, texture coordinates and data confidence values. The format permits one to have different properties for the front and back of a polygon.\(^2\) There are two versions of the PLY file, one in ASCII, the other in binary format.

With respect to editing the point cloud, there are some simple selection tools that allow one to highlight and delete points as necessary using the select vertices icon and the delete vertices icon. There is also a layers feature that makes selection and visibility of individual meshes possible. This is available from the layers icon and brings up a small window on the right side of the 3D Viewer window as shown below:
Figure 4. Layers window active with all layers turned on.

From this window you can add or delete layers, plus there is a small contextual window at the bottom that gives you specific information about each of the processes that are run on any point cloud or mesh.

**Meshing**

The two most popular meshing options in MeshLab are the Poisson and Ball Pivoting methods of surface Poisson reconstruction from a point cloud. The Poisson reconstruction is often used when a water tight mesh is needed. Using this method for point clouds that are not completely closed can often give a lot of artifacts on the edges where the algorithm tries to wrap around the object to create a fully closed mesh.

Figure 5. Point cloud of a stone turtle prior to Poisson meshing.
The Ball Pivoting Algorithm (Bernardini et al. 1999) starts with a seed triangle, the BPA algorithm pivots a ball around an edge (i.e. it revolves around the edge while keeping in contact with the edge endpoints) until it touches another point, forming another triangle. The process continues until all reachable edges have been tried.

There is a good tutorial on meshing and preparing a point cloud for surface reconstruction [here](#).

**Importing Photosynth Point Clouds**

Another interesting option in MeshLab is the ability to import a Photosynth point cloud directly into the 3D Viewer without having to use a third party application. Directly inside the Filters menu and under Create New Mesh Layer, you will find an option for Import Photosynth Data.
Figure 7. Import Photosynth Data under the Create New Mesh Layer sub-menu item.

This brings up a very simple menu where you can enter the URL of the created Photosynth and there is an option to download the images plus calculated camera positions. A sample URL will look like the following:

http://photosynth.net/view.aspx?cid=49c5c1e9-1d19-4edd-91af-b86318a774f2

Figure 8. Import Photosynth Data window.

It’s important to remember that in the “Save to” line, ensure that the directory you are saving to already exists. When completed filling out the fields, click “Apply” and the points should be imported directly from the Photosynth server. Note that you must select the icon so you can see the vertices/points. At this time, only points are imported and not the RGB color information. For better viewing, it also helps to turn off the default lighting (click the icon).

Figure 9. Imported Photosynth into MeshLab.

Sampling
Although MeshLab can handle millions of points, many of the processes take a long time and you will find it much easier to simplify or decimate the point cloud by using the tools in the Sampling menu. As an example by using the previously imported point cloud of the skull (above) from Photosynth, there are
currently over 36,000 points. Although this is a relatively small point cloud, MeshLab reportedly has a maximum capacity of handling point clouds in the range of 31 million points or thereabouts.

![Figure 10. Sampling menu](image)

In the top of the Sampling sub-menu is a feature called “Clustered Vertex Subsampling”. This is a decimation algorithm that will reduce the size of the point cloud. Many of the other options in the Sampling sub-menu are for meshes only and will not work on point clouds.

![Figure 11. Clustered Vertex Subsampling window.](image)

Using the default values will result in Figure 10. The larger the values of the “Cell Size”, the greater the amount of decimation. Often experimentation is required to get the desired amount of reduction in points.
Registration

Registration is possible through the Align icon which brings up a contextual menu as follows:

Figure 13. Align menu for registration of scans.
There are 3 key concepts to registration.

**ICP:** The basic algorithm that automatically precisely aligns a moving mesh M with a fixed one F. The main idea is that we choose a set of (well distributed) points over M and we search on F for the corresponding nearest points. These pairs are used to find the best rigid transformation that brings the points of M onto the corresponding points of F. ICP has a lot of tunable parameters.

**Global Alignment:** This is also known as multi-view registration; a final step that evenly distributes the alignment error among all the alignments in order to avoid the biased accumulation of error.

**Absolute Scale:** The parameters of the alignment tool are in absolute units, and the defaults are acceptable for a standard scanner outputting meshes in millimeter units. So for example the target error (i.e. the error that the ICP try to achieve) is 0.05 mm something that can be achieved with a good scanner. If your range maps are in a different unit (microns, kilometers,...etc.) you must adjust the default alignment parameters or the alignment process will fail.

Overall, there are many other useful features in MeshLab and it’s a matter of testing and tweaking. Unfortunately, the documentation isn’t always the greatest, but there are some YouTube videos and Blogs around that provide some decent information. There is also a user’s forum where you can post issues or ask questions about specific features, however, nothing beats just trying the software out with your own sample data sets.

---

Eugene Liscio, P. Eng, is the owner of AI²-3D. A company that specializes in 3D Forensic Measurement, Analysis and Visualizations. Eugene is also the President of the International Association of Forensics and Security Metrology (IAFSM) and a member of the American Society of Photogrammetry and Remote Sensing. AI²-3D, Toronto, Ontario, 416-704-2695, information@ai²-3d.com, www.ai²-3d.com.