Building a Low-Cost Whole Slide Imaging (WSI) System in a Basic Research Lab: Lessons and Successes

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Abstract

I. Background: There is increasing interest in merging molecular "omic" data (e.g., DNA mutations) with histopathology findings[1, 2]. Whole slide imaging (WSI) systems enable such integrative studies. However, commercial WSI solutions are highly expensive. We custom-built a WSI station in our lab using low-cost hardware to enable an end-to-end digital pathology (DP) workflow.

II. Methods: Major components of our custom-built WSI workstation are a) Microscope: We used a CH30 Olympus Microscope b) Camera: We used a Point Grey GS3-PGE-23S6C-C Grasshopper3 GigE camera with a Sony IMX174 1/1.2" chip c) Hardware: We built an Intel Core i7-9400 CPU Linux desktop with 24GB RAM memory and a GTX1070 NVidia graphics card d) Software: We used MATLAB to implement the SIFT-RANSAC image mosaic algorithm e) WSI Storage: Open source OMERO setup was used to store the WSI images in a 2TB NAS back up.

III. Results: Our WSI imaging system is shown in Figure 1. We built the WSI set-up at a low price point (~$2500). MATLAB software and the homography relating SIFT-RANSAC image algorithm was used to create WSI mosaics in the DP workflow. Our workflow enables manual capture, global alignment, image blending and local adjustment to create the final WSI mosaic. The OMERO software is a convenient way to manage and view WSI composites on demand.

IV. Conclusions: We built a low-cost DP workflow in our research lab. Manual WSI workflows are feasible with increasingly cheap optical components at a low price point.

WSI Setup Components

WSI Imaging Components

WSI components	Details	Price/Source
Computer	Intel(R) Core(TM) i7-9700 CPU @ 3.00GHz	$400
	24GB DIMM DDR4 Synchronous RAM	$80
	NVidia GTX1070 Graphics Card (6 GB)	$200
	Computer peripherals	$200
Microscope	Olympus CH30 Microscope	Dept. surplus
	Olympus 4x, 10x, 20x, 40X objectives	eBay - $600
	Olympus trinocular head	eBay - $300
Software	Linux Ubuntu 18.04 LTS OS	Open Source GPL
	MATLAB v.20.02	University, free
	OMERO – Open Microscopy Environment	Open Source GPL
Other	3' x 2' Granite base	Local business gift
	Phillips 27" monitor	$250
	Hard Disk Storage	$300

WSI Imaging Components Key Lessons:

- A majority of the components required to enable a home-built WSI system are often readily available in Pathology departments
- It is significantly cheaper to custom-build a computer to high specifications than purchase a commercial readymade computer
- We used an old Olympus CH30 microscope in our WSI platform build. Older generation microscopes have an objective focal length of 160 mm which is a disadvantage while focusing
- If available, it is preferable to use infinity corrected objectives (present in newer model microscopes and expensive)
- eBay is an excellent resource for many components to reduce costs

CMOS Cameras

Basler acA1920-40GC | PointGrey GS3-PGE-23S6C-C | Pixelink D7512 CU

Feature	Basler	PointGrey	PixelLink
CMOS Sensor	Sony IMX249	Sony IMX174	Sony IMX253
Sensor Size	11.3 x 7.1 mm	11.3 x 7.1 mm	17.6 mm (dia)
Pixel Pitch	5.86 x 5.86 µm	5.86 x 5.86 µm	3.45 x 3.45 µm
Resolution	2.3 MP	2.3 MP	12.29 MP
Frame Rate (max resolution)	42 fps	48 fps	34.7 fps
Shutter	Global	Global	Global
Camera Interface	USB 3.0	GigE	USB 3.0
Retail/eBay Price	$524/$300	$1045/$120	$3295/$300

CMOS Camera Key Lessons:

- Industrial CMOS cameras are available in a variety of end-user specifications which can be repurposed for WSI
- Key factor of WSI CMOS camera image quality are the pixel pitch (larger pitch is better). Total resolution is not a significant factor (more megapixels is not necessarily better)
- CMOS vendors provide software APIs that are cross-OS compatible (e.g., Linux and Windows)

WSI Algorithm

WSI workflow

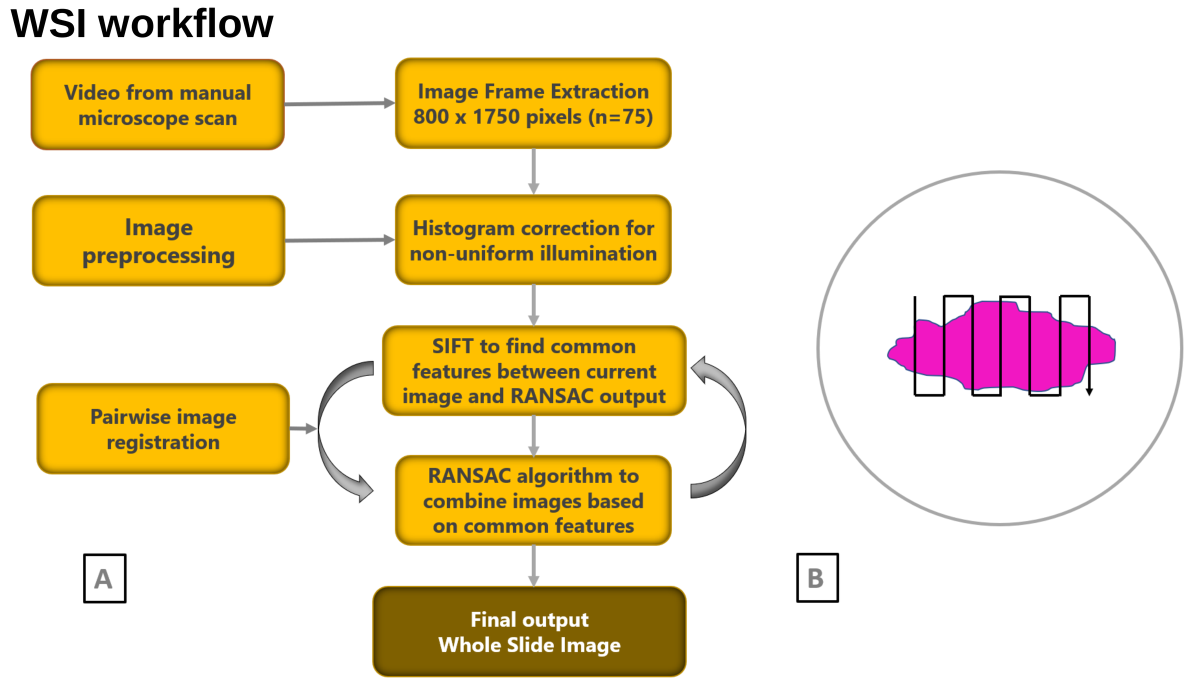


Figure 1. WSI algorithmic workflow: A. A schematic illustrating the custom built WSI workflow in the lab. Image sizes and final WSI composites are highly customizable depending on the area of tissue that needs to be scanned. B. A scanning pattern of an area of tissue. The overlap area while scanning the histology tissue in either direction needs to be ~50% to get accurate WSI composites.

SIFT Algorithm

- Also known as the scale invariant feature transform (SIFT)
- An image processing algorithm to detect salient, stable feature points in an image
- The feature points are invariant to rotation and scale
- A very useful algorithm to measure affine transformation/homography between images
- In our pipeline, SIFT is used to match the successive histology images obtained from a continuous video sequence while scanning manually the H and E slide

WSI Algorithm (contd.)

RANSAC Algorithm

- Step II uses the RANdom Sample Consensus (RANSAC) algorithm
- RANSAC is a resampling technique to match points generated by SIFT from an image according to a linear regression model.
- RANSAC helps to identify the image sequence which form the final WSI composite.

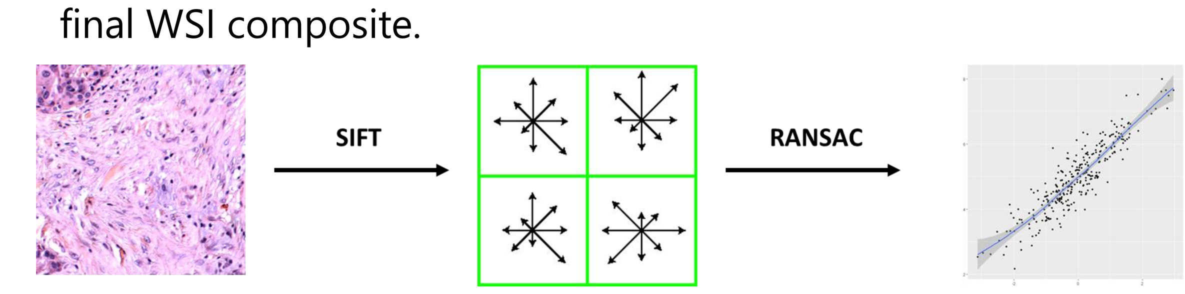


Figure 2. SIFT-RANSAC: A schematic illustrating the SIFT transform followed by RANSAC model fit for a single H and E image

Results

I. Home-built WSI Workstation

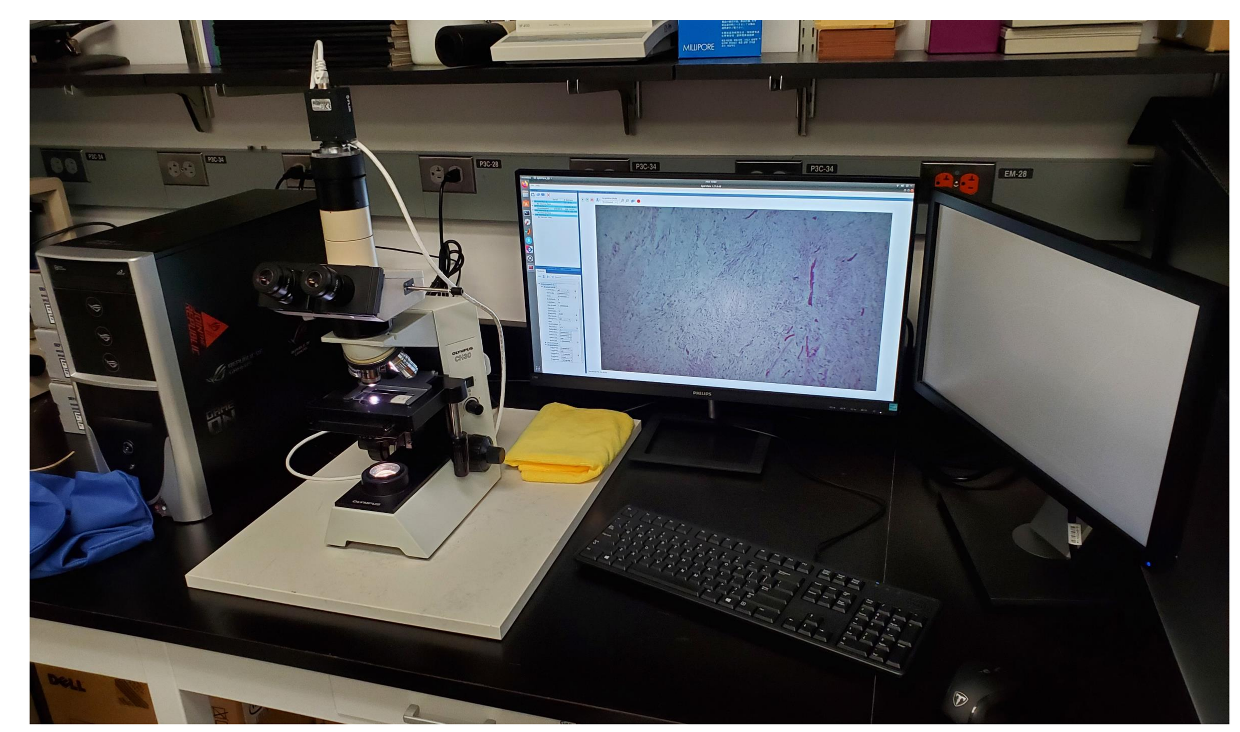
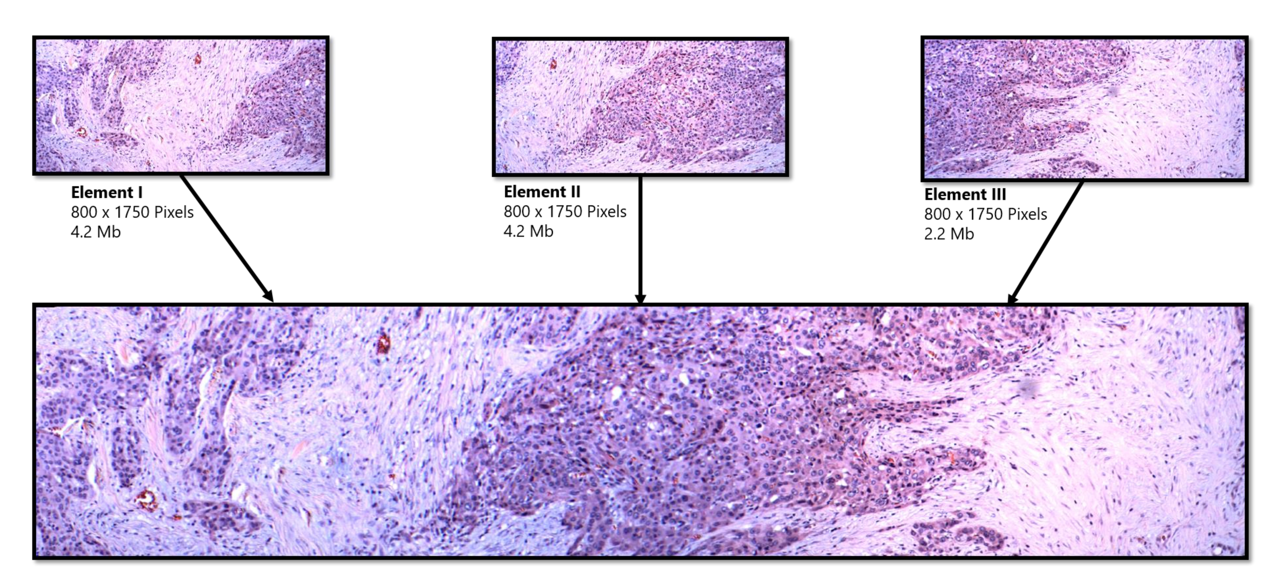


Figure 2. WSI workstation: The final WSI set up occupies a spatial foot print of 5' x 3' bench space. Major components (L-R) of the WSI set up include a) Linux workstation b) Olympus CH30 Microscope and c) dual monitor screen set up. The microscope is placed on a heavy granite slab base (white) to reduce vibrations and increase stability of WSI acquisition.

II. WSI creation using the SIFT-RANSAC algorithm



Sample Composite Whole Slide Image - 1194 x 5840 Pixels, Disk Storage Space – 37.3 Mb, 600 dpi

Figure 3. Creation of a composite WSI image: In this example WSI workflow, we imaged an H and E slide of Gallbladder Carcinoma. The slide was imaged using our PixeLink CMOS camera to create a .mp4 movie sequence of 7.5 seconds. The total number of frames in the movie were n=75 images. TIFF images were created first followed by intensity correction afterwards. The separated images were relabeled sequentially and stored in a folder. The SIFT-RANSAC algorithm was applied on this sequence to assemble the final composite WSI. The final image was ~1194 x 5840 pixels in this example and 37.3 Mb size at a 600 DPI resolution.

Results (Contd)

Additional Image Stitching Software Evaluation

- Prior to building our custom-built WSI analysis pipeline, we examined alternative software to enable WSI image composites such as: ImageJ plugins, HUGIN software, Microsoft Image Composite editor, Microscopy Image Stitching Tool (MIST)
- These solutions can enable composite image creation. However, they are limited in their customization flexibility

WSI Storage and Backup

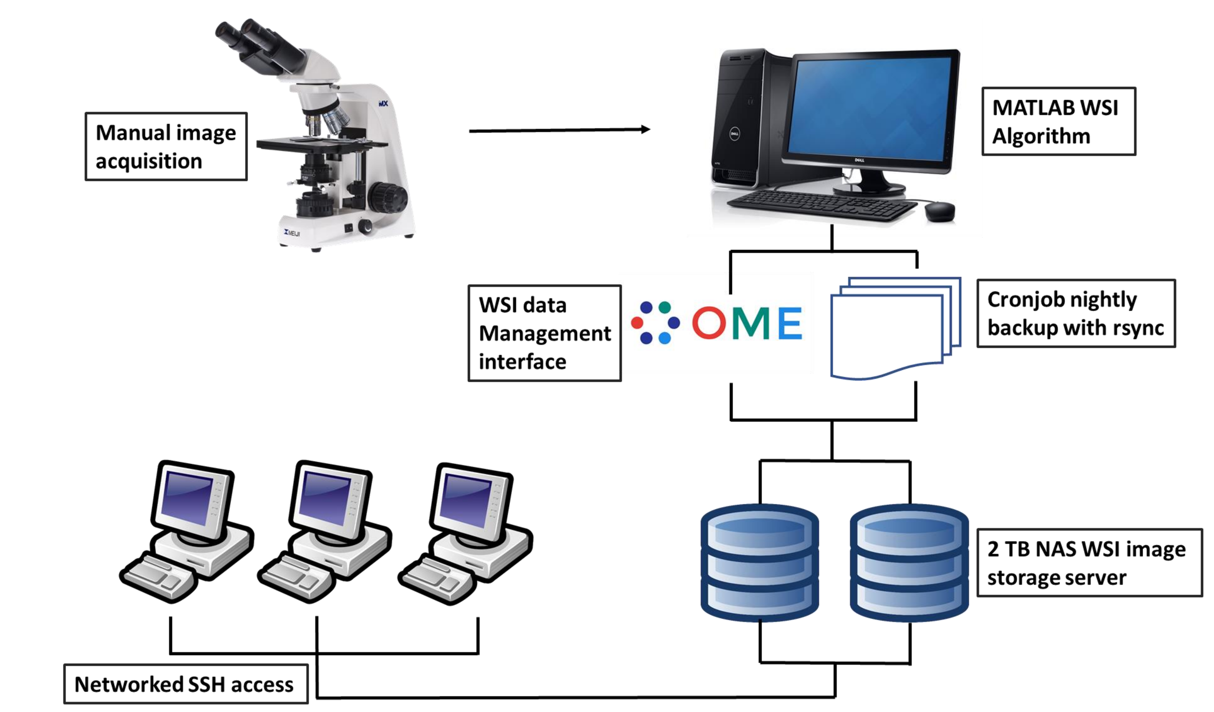


Figure 4. WSI storage workflow: A schematic illustrating storage aspects of our custom WSI workflow set up.

WSI Storage Key Lessons:

- Linux OS has powerful back up software (e.g., **crontab** and **rsync** commands simplifying the data back up process
- Java based Open Microscopy Environment (OME) has powerful cross OS compatible packages like OMERO to enable WSI data management
- Digital storage (e.g., external hard drives and networked access storage (NAS) is increasingly cheap enabling the storage of big data WSI images

Conclusions

- There is an increasing need for digitization of histology slides in research labs. However, commercial WSI systems are expensive for a research lab to acquire.
- We constructed an end-to-end DP workflow using low-cost components that are easily available
- We used MATLAB and Linux as the core components of our software pipeline. Multiple open-source software resources exist to create a home-built WSI pipeline similar to ours
- Low-cost CMOS cameras with excellent image acquisition characteristics are increasingly available to create similar home-built WSI systems
- The OMERO open-source WSI data management system is a robust and versatile solution for the big data management needs of WSI imaging

References

1. Gullapalli et al, (2012) J Pathol Inform. 2012; 3: 40
2. Gullapalli et al, (2012) Clinics in Lab Medicine, Vol 32, 585-599

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