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Digitizing an Analog Radiography Teaching File Under Time Constraint: Trade-Offs in Efficiency and Image Quality

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Abstract We digitized the radiography teaching file at Black Lion Hospital (Addis Ababa, Ethiopia) during a recent trip, using a standard digital camera and a fluorescent light box. Our goal was to photograph every radiograph in the existing library while optimizing the final image size to the maximum resolution of a high quality tablet computer, preserving the contrast resolution of the radiographs, and minimizing total library file size. A secondary important goal was to minimize the cost and time required to take and process the images. Three workers were able to efficiently remove the radiographs from their storage folders, hang them on the light box, operate the camera, catalog the image, and repack the radiographs back to the storage folder. Zoom, focal length, and film speed were fixed, while aperture and shutter speed were manually adjusted for each image, allowing for efficiency and flexibility in image acquisition. Keeping zoom and focal length fixed, which kept the view box at the same relative position in all of the images acquired during a single photography session, allowed unused space to be batch-cropped, saving considerable time in post-processing, at the expense of final image resolution. We present an analysis of the trade-offs in workflow efficiency and final image quality, and demonstrate that a few people with minimal equipment can efficiently digitize a teaching file library.

Keywords Workflow · Teaching · Radiology teaching files · Productivity · Image quality · Human-computer interaction · Electronic teaching file · Efficiency

Background

Black Lion Hospital (BLH) in Addis Ababa is the primary training site for radiologists in Ethiopia. Radiologists at BLH have maintained a teaching file of printed radiographs and hardcopies of CT, MR, and US, depicting a range of pathologic, normal variant, and otherwise interesting cases spanning approximately 30 years. The teaching file is organized using a four-part alphanumeric system identifying cases by organ system, disease category, and specific diagnosis (Table 1). The reference table of contents is kept in a manual log book. This teaching file serves as a primary study resource, particularly for the third year residents preparing for their board exam.

Organizing and maintaining such an analog system takes considerable effort to battle entropy [1, 2]. Films easily go missing or are filed in the incorrect folder. The log book does not allow for easy reorganization and is physically deteriorating. Previous efforts to digitize the BLH library have been unsuccessful due to the perceived complexity of the task and inadequate image quality of a point-and-shoot style digital camera.

Digital cameras are adequate for developing teaching files [3]. High quality digital images of radiographs preserve diagnostic quality compared to the original hard copies [4–6] and are comparable to more expensive flatbed scanners and film digitizers [7]. More recent studies have shown that even

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Table 1 The teaching file is organized using a four-part alphanumeric system that replicates the existing manual log book. The top level categories are generally major organ systems, followed by general categories of diseases, and then specific diagnoses. Category 1.1 is expanded in this example to show the specific diagnoses. In the image library, chest radiographs of patients with aortic stenosis are labeled 1.1.2a, 1.1.2b, etc.

1. Cardiovascular
1.1. Acquired heart disease
1.1.1. Aortic insufficiency and mitral insufficiency
1.1.2. Aortic stenosis
1.1.3. Cardiomyopathy
1.1.4. CHF
1.1.5. Heart in anemia
1.1.6. Heart in anemia (thalassemia)
1.1.7. LV aneurysm
1.1.8. LVH
1.1.9. Mitral stenosis and insufficiency
1.1.10. Prosthetic cardiac valves
1.1.11. Pulmonary edema
1.1.12. Ventricular aneurysm calcification due to MI
1.2. Congenital heart disease
1.3. Pericardial diseases
1.4. Vascular disease
2. Chest
2.1. Collapse and consolidation
2.2 Inflammatory lung diseases
2.3. Mediastinal diseases
2.4. Miscellaneous
2.5. Pediatric chest diseases
2.6. Pleural diseases
2.7. Tumors
3. CT
3.1. Abdomen
3.2. Brain and spinal cord
3.3. Chest CT
4. GI
4.1. Biliary tract
4.2. Esophageal diseases
4.3. Large bowel disease
4.4. Liver, spleen, and pancreas
4.5. Pediatric GI
4.6. Plain abdomen
4.7. Small bowel diseases
4.8. Stomach and duodenum
5. GU
5.1. Congenital abnormalities
5.2. Gynecologic problems
5.3. Miscellaneous
5.4. Tumors
5.5. Urethrography
6. Musculoskeletal
6.1. AVN
6.2. Benign bone tumors
6.3. Congenital bone diseases
6.4. Facial bones, teeth, and jaw
6.5. Hematopoetic bone disease
6.6. Infections
6.7. Joint diseases
6.8. Malignant bone tumors
6.9. Metabolic bone disease
6.10. Metastases to the bone
6.11. Miscellaneous
6.12. Myelography
6.13. Pharynx, larynx, and sinuses
6.14. Skeletal trauma
6.15. Skull pathology
6.16. Soft tissue calcification and tumors
6.17. Spinal pathologies
6.18. Ultrasound

smartphone camera pictures of radiographs are of sufficient quality for detection of the presence or absence of major abnormalities, and frequently allow for a specific diagnosis [8]. We worked with residents and attendings at BLH to digitize the entire BLH teaching file library during a recent visit and present here an analysis of trade-offs between efficiency and image quality we encountered.

Methods

We estimated that there were 1500 radiographs in the library, and we had 6 days with up to 4 h per day to work (maximum allowable time ~24 h). The final images were going to be viewed on standard desktop monitors, laptops, and mobile devices. Since most residents at BLH have Android tablets, we used the screen resolution of these devices at the time of our project, 2560 × 1600 pixels, as an optimum target. A 16.1-megapixel camera with an Exmor APSC CMOS sensor (Alpha NEX6, Sony Corporation) and a 16–50-mm zoom lens was set on a tripod in a darkened room. Zoom and manual focus were set to show the full length and width of a standard fluorescent light box from approximately 1.5 m away. Camera settings were fixed to black-and-white 8-bit JPEG format at maximum camera resolution, and ISO 100 equivalent film speed to minimize noise. Aperture and shutter speed were manually adjusted to optimize contrast resolution for each image, determined subjectively by the camera operator (Fig. 1).

To minimize cost, we preferred to use free open-source software for image manipulation. JPEGCrops (freeware; v0.7.5 beta) was used to batch crop the digital image files to isolate the fluorescent light box from the background (estimated time required: 2 h). The GNU Image Manipulation Program (freeware; v2.8.14) was used to manually obscure

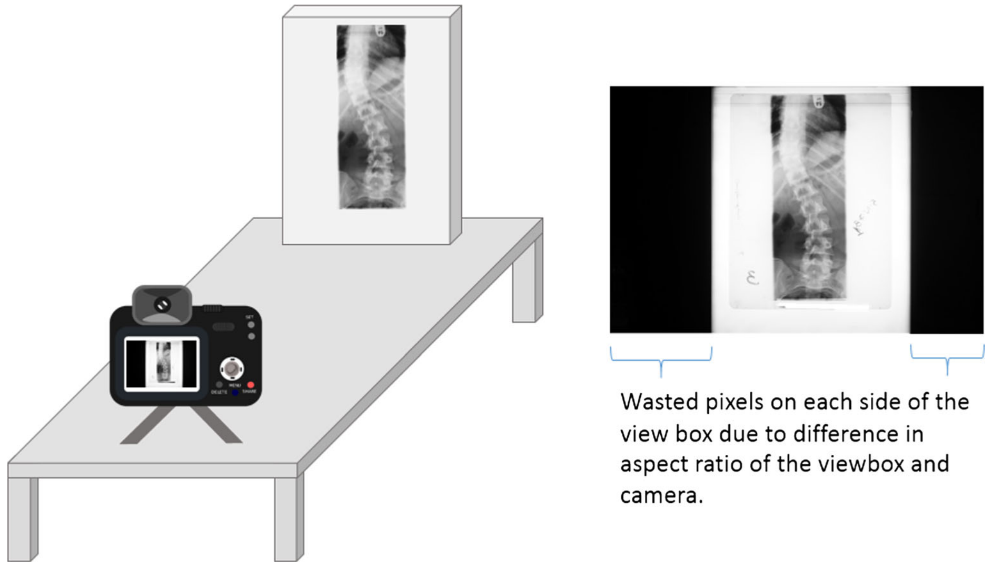

Fig. 1 Example of the setup and resulting images. For the sake of efficiency, the camera was not reoriented or zoomed to crop out wasted space on the sides of the view box and radiograph at the time of acquisition. The relevant portions of the image were still of sufficient resolution for their intended viewing on desktop PCs and tablets

identifying patient information from the digital files (5 h), as well as to further crop each image to isolate the radiograph from the light box (3 h). Microsoft Excel and Access (commercial; Office 2013 edition) were used to process data and develop a database interface for the digital teaching file.

File creation timestamp was extracted from the digital image files using ExifTool (freeware; v9.69). Final image resolution and bit depth were extracted using ImageJ (freeware; v1.48) with the Batch Statistics plugin.

Results

Including setup time and short breaks/interruptions, photographing 1438 radiographs from the library took 6 h and 10 min divided into six sessions, with up to four people working at any given time. All of the workers were radiology resident volunteers, two from Ethiopia and two from the United States of America. The first person operated the camera and logged the alphanumeric code to a spreadsheet. The remaining tasks were shared by the other available workers, and included removing films from their storage folders, orienting them for hanging, calling out the alphanumeric code, hanging the films on the light box, and placing them back in the storage folder. If a photograph needed to be repeated, the code was simply entered again in the spreadsheet, in order to

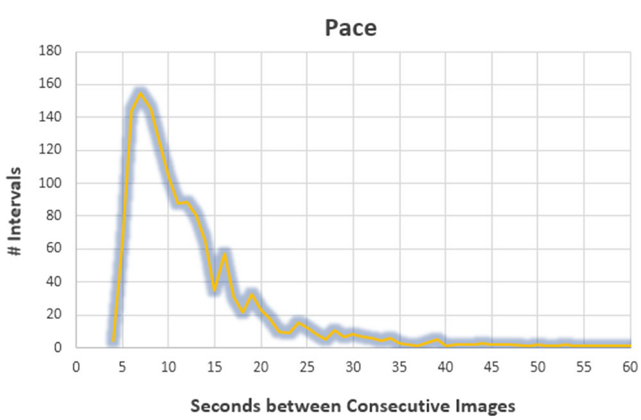

Fig. 2 Distribution of the number of seconds between consecutive images. Most such intervals (>90 %) were less than 23 s, with an average of 13 s and mode of 7 s

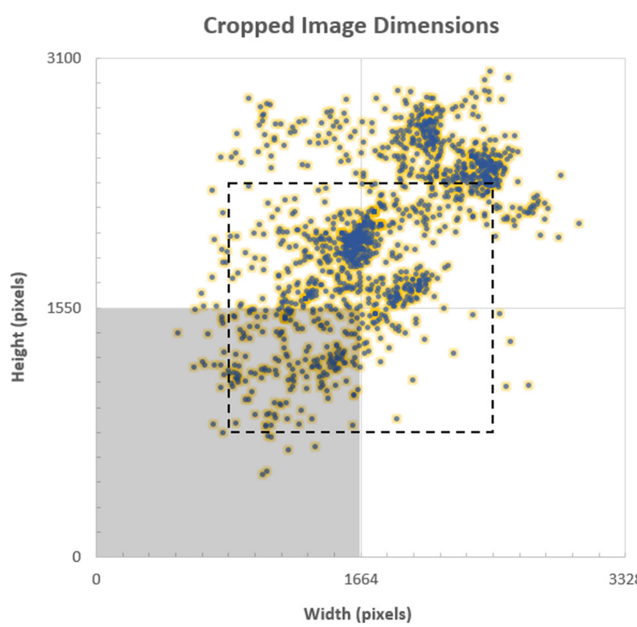

Fig. 3 Dimensions of the final cropped images. The target size was 1664 × 1550 pixels to optimize display on high-resolution Android tablets. Images significantly smaller than this may be of too low resolution, while images significantly larger that this (*above and to the right of the shaded area*) may result in unnecessarily large file sizes. Sixty-four percent of the images were within 50 % of the target resolution (*hash-marked box*) while only 15 % were of lower resolution (*shaded area*)

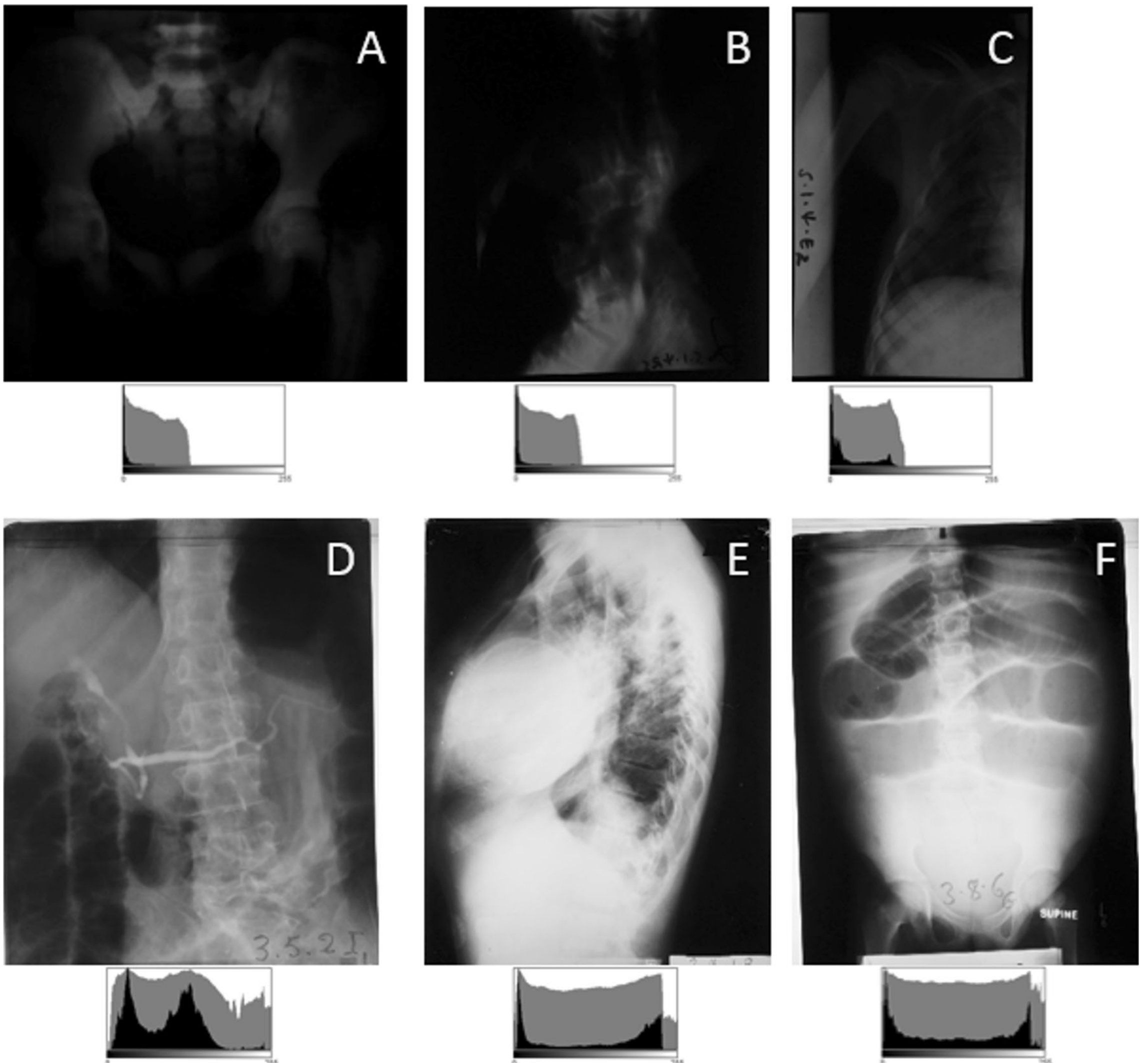

Fig. 4 Example of three images with the lowest dynamic range (with 107, 110, and 122 shades of gray, respectively (**a**–**c**)), and three images randomly chosen from among those with the full 256 shades of the 8-bit grayscale (**d**–**f**). The images with lower dynamic range are of subjectively worse quality. The histogram below each image shows the distribution of pixel intensities throughout the grayscale, on a standard (*black*) and logarithmic *y*-axis (*gray*)

preserve the direct 1:1 relationship between the spreadsheet entries and the images on the camera, which facilitated cross-referencing the digital images to the alphanumeric codes during later steps. The need for repeat images was determined subjectively by the camera operator at the time of image acquisition by comparing digital image quality to hardcopy quality. If the digital image faithfully reproduced the appearance of the hardcopy, even if the hardcopy itself was of poor quality, the image was considered adequate. Using this system, we were able to process one image every 13 s on average (Figs. 2 and 3 mode = 7 s 90 % ≤23 s). Twenty-seven repeats were obtained due to poor initial quality (1.9 % of 1438 radiographs).

Full dynamic range of 8-bit grayscale images is 256 (2^8) shades of gray. After cropping, the average digital image had an average of 232 shades of gray. Assuming that the ideal

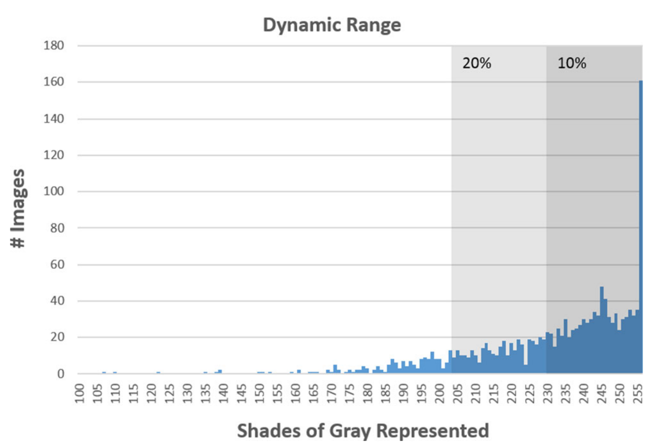

Fig. 5 Dynamic range of the final cropped images. The average image has 232 shades of gray, 91 % of the full 8-bit grayscale range. Eighty-eight percent of the images were within 20 % of the maximum range of 256 shades of gray

digital representation of a radiograph includes the full gray-scale range (Fig. 4), the average image reached 91 % of this idealized target. 161 (11 %) had the full range of 256, while 64 % were within 10 % and 88 % were within 20 % (Fig. 5).

The camera zoom was fixed, rather than optimized for each film. While manually adjusting the zoom so that each radiograph would occupy the maximum possible portion of the camera sensor would have maximized the final image resolution, it would have taken considerably more time. Keeping the zoom fixed resulted in the radiograph occupying less than the full 4912 × 3264 (16,032,768) pixels of the camera sensor (see Fig. 1). The digital images were subsequently cropped to remove the unused space, resulting in average final image dimensions of 2001 × 1785 (3,571,923) pixels, 22 % of the maximum possible resolution of the camera.

The optimum target resolution was arbitrarily determined to be that which maximally fits on a high-resolution Android tablet in landscape orientation. On a tablet with a screen resolution of 2560 × 1600, the screen height in landscape mode is 1550 pixels with the top 50 pixels reserved for the system notification bar. An image of higher resolution than this will be down sampled for display, so there is no significant benefit to storing images at higher resolution. In order to optimize spatial resolution, the images should be equal to or higher than screen resolution, and in order to minimize storage space, they should not be significantly higher. Sixty-three percent of the final cropped images were within +/50 % of the target resolution (hash-marked box in Fig. 3), and only 15 % were lower than the target (shaded area in Fig. 3).

The raw image library was 2.17 GB before cropping (average image size = 1.51 MB), and 818 MB after cropping (average 597 kB).

The images were organized using the same numeric coding system of the existing hardcopy library and log book (Table 1). The Access database is navigated using a simple form, which also displays the images (Fig. 6). The user can double-click on an image to open it in the default PC image viewer application, and can submit quality control feedback on each image using a series of buttons. This will allow for ongoing quality control to identify specific images that should be repeated or, if the source radiograph is itself of poor quality, specific diagnoses that need new example radiographs.

The total cost of our project, with no existing equipment, is $750, allowing $400 for the camera, $250 for a PC, and $100 for Microsoft Office, and by making use of free open-source software for image processing.

Discussion

We efficiently converted a hardcopy film-based teaching file to digital format using a workflow that required only basic knowledge of digital camera operation, image processing, and database development.

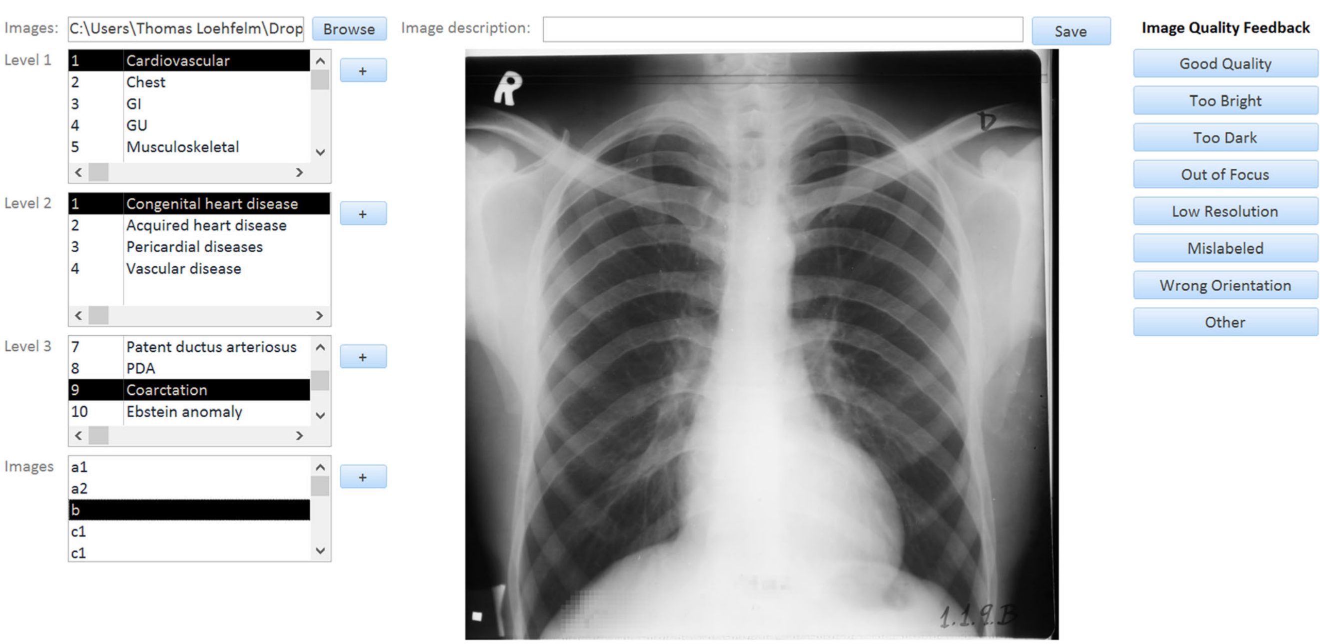

Fig. 6 Screenshot of the Microsoft Access database form used to navigate the teaching file. The user selects the category and specific diagnosis using list boxes. The image is displayed on the form, and can be double-clicked to launch the default PC graphics viewer, which allows more advanced image manipulation tools such as zoom and brightness/contrast adjustment. A series of buttons along the right side of the form allow each user to submit quality control feedback to monitor image quality and highlight images and diagnoses that require revision

Radiologists at BLH created their teaching files in order to organize and pass on diagnostic imaging cases that are garnered from the local and regional population, and therefore likely to be relevant to that same community, in a way that other accessible libraries, including online materials, might not be. This is particularly true for rare diseases, or rare presentations of common conditions that might not present during the 3-year residency of an Ethiopian radiologist. The teaching files are also representative of the imaging modalities and techniques that are most frequently used at BLH, such as radiography and ultrasonography.

Building and maintaining a hardcopy teaching file can be resource-intensive, requiring ongoing investments in film, developers, and filing systems. At BLH, where patients own their radiographs and take them home when they leave, keeping a copy for the teaching file requires film duplication equipment. At the time of our visit, the film duplicator was not functional, so the library could not be expanded. Films can be lost, damaged, and filed in the incorrect location, and are only available to one person at a time. A digital library is more accessible and easier to organize and maintain. Digital files can be easily copied and shared, and are consumable on a variety of devices, including smartphones and tablet computers, which are in widespread use among Ethiopian radiology trainees.

Our system requires only modest investments of money and time. Some of the components, such as a light box, PC, and Office suite of software, were already available at the hospital. A good quality digital camera is essential. The model we used can be purchased for approximately $400. We made use of free open-source software for image processing. If Microsoft Access were not already available on the target PCs, we could have used open-source database tools to replicate the same functionality. We performed all of the work onsite in Ethiopia, and under time constraint. With more time, we would have preferred to implement the teaching file as a website, which would facilitate remote technical support and quality control, and allowed for ongoing additions of cases and other enhancements. Maintenance of such a site would require more infrastructure and modest expenses to host the site.

Our system does require basic knowledge of digital camera use and database design to implement, which limits its applicability. While most of the images are subjectively adequate for teaching purposes, they are likely not of diagnostic quality. Image quality could be optimized in a setting where time is not a factor. We chose arbitrary targets for final image resolution and are relying on the surrogate marker of grayscale range as an indicator of image quality. To address these limitations, we built quality control feedback tools into the design of the teaching file database, and are in the process of gathering data on end-user perception of image quality.

Conclusion

A hardcopy film-based teaching file can be digitized in an efficient and cost-effective manner with four workers, a good quality digital camera, standard fluorescent light box, and a PC with standard Office software. The resulting digital library is more accessible and portable, and easier to maintain than the hardcopy version.

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