PANORAMA-BASED CHANGE DETECTION PROCESS: A PILOT STUDY ON CHALLENGES AND SOLUTIONS

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Abstract: Researchers at the University of New Brunswick provide a means to document and display the progress of construction projects through panoramic images. The introduction of change detection within panoramas facilitates progress monitoring by identifying areas within the panoramas which have changed since the last capture date. This paper investigates change detection challenges and solutions to improve current panoramic change detection process. To reach this goal, a pilot study is conducted which identifies and evaluates photography and post-processing change detection variables. Adobe Photoshop is used to perform all post-processing. Areas of change within panoramas are identified using pixel based intensity differencing. The resulting change image is overlaid on the original image, highlighting changed objects and providing insight on construction progress. Change detection begins with two panoramas taken from the same location on different dates with enough time elapsed so that visible changes are evident. Research reveals that while panoramic change detection techniques produce acceptable results, they still require a significant amount of input and judgment from the user. Therefore, expanding the current status of panoramic monitoring systems through pixel based change detection is still impractical, and there is an opportunity for further research in this area.

1 INTRODUCTION

Research has been conducted on panorama-based virtual reality technologies for monitoring construction projects. Rankohi et al. (2014) assess the efficacy of virtual reality technologies over traditional methods of monitoring construction projects by conducting a pilot study on a web-based panoramic as-built documenting system. Dang et al. (2011) proposed a panorama-based semi-interactive 3D reconstruction framework for indoor scenes. Their framework overcomes the problems of limited field of view in indoor scenes and has the desired properties of: robustness, efficiency, and accuracy. Bradley et al. (2005) present a system for virtual navigation in real environments using image-based panorama rendering. Shum et al. (1998), Li et al. (2004), Haeusler et al. (2008) also conducted research on 3D reconstruction from digital panoramas.

Construction researchers at the University of New Brunswick provide a means to document and display the progress of construction projects through panoramic images. Unlike traditional onsite photography, 360 degree panoramic images provide users with an intuitive interface for virtually visiting construction sites and create a comprehensive photographic record. The introduction of change detection within panoramas expands on the current virtual site visit functionality; facilitating progress monitoring by identifying areas within the panoramas which have changed since the last capture date. Areas of change are identified using pixel based intensity differencing. The resulting image (the change mask) is overlaid on the original image, highlighting changed objects and providing insight on construction progress. The overlay facilitates the visualization of additions as well as subtractions to the structure and site.

Photography requirements for change detection are similar to those for panoramas. Twelve images are captured at a single location and then converted into a single panorama during post-processing. Change detection begins with two panoramas taken from the same location on different dates with enough time elapsed so that visible changes are evident. Apart from the creation of the panoramas, Adobe Photoshop is used to perform all post-processing. Within Photoshop, two panoramas to be compared are placed on separate layers. The panoramas must be aligned to account for any variation in the initial direction of the camera. Once aligned, the change mask is created by blending the two layers using the differencing blend mode. Both "important" changes such as construction progress, as well as "unimportant" changes such as lighting conditions, will be displayed on this mask. Removing the unimportant changes from the mask is achieved through the use of various tools and filters described in the following sections.

2 DESCRIPTION OF VARIABLES

Several variables having significant influence on change detection by differencing were identified and placed into two categories, photography related and post-processing related. Table 1 shows photography and post-processing related variables.

Table 1: Photography and post-processing related variables

Variables	Challenges
Photography Variables	*Camera location* *Objects* *Detected details*
Post-processing Variables	*Lighting condition* *Objects(size and color)* *Small changes* *Camera location*

Camera location refers to whether the camera was at different locations between the first and second image. Moving the camera introduces parallax errors as well as a change in the size of objects. This results in registration errors when the two images are overlaid for comparison. Objects in each image no longer align and although corrections can be applied, significant movement introduces irreparable parallax errors which in turn cause false change detection. The distance of *objects* relative to the camera describes the amount of *detected details* and ultimately depends on how many pixels the object occupies in the image.

Post-processing tools remove unimportant changes by eroding pixels until the change is removed. Effective detection requires that the *objects* be greater in size than that required by the erosion process. Otherwise the change mask will include a significant number of pixels detected in error or be excluding important changed objects. *Object* color is also significant when similar colors between an object and background have similar intensity values, thus producing negligible change after differencing pixel values. The greater the difference in color between change object and background, the easier the detection becomes. Post-processing requirements will also be less intense providing more confidence in the change mask. After photography is complete, post-processing techniques are used to implement change detection. Varying *lighting condition* between images poses a problem as image differencing uses the difference in pixel intensity values to detect change. Thus changing the lighting conditions will change the intensity value of pixels and therefore cause false changes to be detected. Shadows and highlights may also be introduced. To overcome this problem, histogram matching can be used as a tool to remove these unimportant changes. One image is chosen as a reference and the histogram of a target image is matched to the reference. The histogram will take on the general shape of the reference image. This technique best corrects global brightness differences between the images. Shadow, mid tone and highlight values of the images will be better aligned but their locations within the image will remain the same. Therefore, significant changes in lighting where new shadows are created will still cause false changes to be detected.

When pixel intensity values are subtracted, pixels which continue to have a value greater than zero indicate change. The greater the value, the greater the change. *Small changes* are easily caused by factors other than moving objects and are considered unimportant in most cases. A threshold allows the user to determine how much difference is required before a change is considered. The threshold can be set anywhere within the pixel intensity range of 1-255. Any pixels greater than the threshold become white and any pixels below become black. White pixels become the basis of the change mask. Once the change mask is created, removing unwanted change from the mask becomes a priority. Unimportant changes occupying a small area relative to that occupied by important changes can be removed using either a smoothing or a contraction and expansion filter. Both techniques erode the edges of selections by a specified amount although each uses a slightly different approach. Smoothing is a one-step process in which pixels are kept if more than half of the surrounding pixels within the specified range are also selected. Contraction and expansion is a two-step process eroding all edges which are then rebuilt by a corresponding expansion filter.

A change in *camera location* greatly affects change detection as it requires the alignment of objects within a scene. Parallax errors are introduced when using images with objects both near and far to the camera. Keeping the camera fixed and using calibrated equipment ensures acceptable results.

3 CHANGE DETECTION PROCESS

A classroom was chosen as the location to demonstrate the effects of each variable and the process of detecting change. Taking into consideration the variables identified, a best case scenario was created. Artificial lighting was used as the main light source so as to keep lighting consistent between images and objects with different colors than the background were used.

Figure 1(a) captures the room in its base state. In Figure 1(b), two chairs were moved from the floor onto the desk at a distance of approximately six feet from the camera. At this distance the legs on the closest chair are 35 pixels wide, while the legs on the farthest are 21 pixels wide. No other changes were made for the second image. Pixel intensity difference can then be determined and the result is the beginning of the change mask. As shown in Figure 1(c), areas with little change will have low values and be dark and areas with significant change will have high values and therefore be bright. The two chairs which were moved are now much brighter than the surrounding unchanged objects. Some errors are evident between objects with high contrast. Possible sources of errors are discussed in (Section 6) difficulties with differencing.

In order to extract areas of change, a threshold is applied which converts the image to black and white. Any value between 1 and 255 can be used. A threshold of 35 was chosen and the results demonstrated in Figure 1(d). This threshold captures the objects that have changed while minimizing the falsely detected changes. The task of selecting the changed area is now a matter of selecting white pixels. It is useful to be able to overlay the changes which have been detected on the original image. Highlighting changes in color facilitates distinguishing changes as shown in Figure 1(e) once overlaid. Stray thin bands or groups of pixels are unlikely to represent change which is important. There are techniques used to remove changes which have been detected in error which remove groups of pixels under a certain size. The smoothing filter examines each selected pixel and compares it to pixels within the specified range. If more than half of the pixels are within the selection, the pixel is retained in the selection. A pixel is excluded from the selection if more than half of the surrounding pixels are not within the selection. Figure 1(f) displays the mask after applying a smoothing filter of 6 pixels.

An alternative to the smoothing filter is a two-step process using a contraction and expansion filter. The contraction filter erodes all edges by a specified amount, which if greater than the size of a group, effectively removes the object from the image. The contraction filter does not distinguish between pixels detected in error and those which were correct. An effective use of the contraction filter will have removed a large portion of the unwanted pixels while maintaining the relative shape of the change objects. An expansion filter is then used to replace the pixels removed by the contraction filter by a value equal to that used for contraction. For both the contraction/expansion and smoothing filters, the size of the object needs to be taken into consideration when determining the amount to be applied. Figure 1(g) displays the mask after a contraction and expansion filter of 5 pixels. The contraction and expansion filters have greatly reduced unwanted change while maintaining the overall shape of the change objects. The final change mask is overlaid on the original image in Figure 1(h).

4 CHALLENGES AND SOLUTIONS

The following section examines each variable independently using panoramas taken in a laboratory setting. Each variable has a base image with which the effects of the variable are compared. Base images were taken in room H135 Head Hall (University of New Brunswick, Fredericton campus) using artificial overhead lighting with one window providing exterior light.

4.1 Threshold

The threshold setting defines at which intensity value pixels are converted to either black or white. Because image differencing relies on pixel intensity values, the threshold can have a significant impact on the change. There is no standard setting for all situations. A threshold setting which is too low increases the sensitivity of change detection, introducing falsely detected pixels. Setting the threshold too high decreases the sensitivity and excludes pixels which have changed. Figure 2(a) shows the base state.

Decreasing the threshold below a balanced setting does not facilitate change detection yet significantly increases errors. Increasing the threshold above a balanced setting reduces errors yet excludes portions of the changed objects. A balanced threshold occurs when the changed objects are largely captured while minimizing errors as displayed in Figure 2(b). Figures 2(c) and 2(d) demonstrate the effects of setting the threshold below and above a balanced condition respectively.

4.2 Distance of Objects

As shown in Figure 3, chairs were placed on the desk further away from the camera to identify the amount of detail which can be detected. It is ultimately the area in pixels that the objects occupy in the image which determines what is detected. Smaller objects begin to resemble the errors which are removed through the contraction filter making them more difficult to detect. The general form of the object must be remaining after the contraction filter is applied in order to return pixels with the expansion filter. More errors remain when detecting smaller objects.

4.3 Similar Color Object and Background

Objects with similar color to their background are difficult to detect as they have similar intensity values. When subtracted, little change is noted. Detecting these objects thus requires a low threshold to increase the detection sensitivity. This in turn increases the amount of error introduced. The tools used to remove error become less effective as the error tends to be in larger groups of pixels rather than thin bands. Removing these large groups of pixels with the contraction and expansion filter is counterproductive as they also begin to remove the change objects themselves. These filters are effective when the objects are much greater in pixel size than the errors being removed. Figure 4 shows the process of detecting changes for objects with similar color to their background.

4.4 Change Light Location

A change in the location of light sources changes the location of bright and dark areas within the image. Shadows and highlights may also be introduced where none were before. Using a threshold of 35 as was used in the images detecting chairs at close range results in significant error when applied in this image with the lights turned off at the back of the room. Given that no objects have moved in this scene, it is expected that no change be detected except for the lights which have been turned off. The threshold is adjusted to 70 so that the lights are just captured in the mask. Errors are significantly reduced in the process. Histogram matching corrects for differences in lighting conditions between images. After matching the histogram in Figure 5(e), there is considerably less error detected.

4.5 No Lights

Turning off the artificial lighting was expected to cause fewer errors than simply changing the location of the lights, as new shadows and highlights would not be created. As shown in Figure 6, using a threshold of 35 produced a significant number of pixels detected in error. Increasing the threshold to 70 as above did not reduce this error nearly as much as expected. Possible causes for this are the window and open door which are creating many highlights and shadows when the lights are turned off.

5 ON-SITE TESTING

Preliminary testing on a construction site was done to implement all of the processing techniques discussed. Joists were the objects being detected at a distance of approximately 30 m, giving them a pixel size of 7-9 pixels wide. Other unimportant moving objects on site were two zoom booms and one crane.

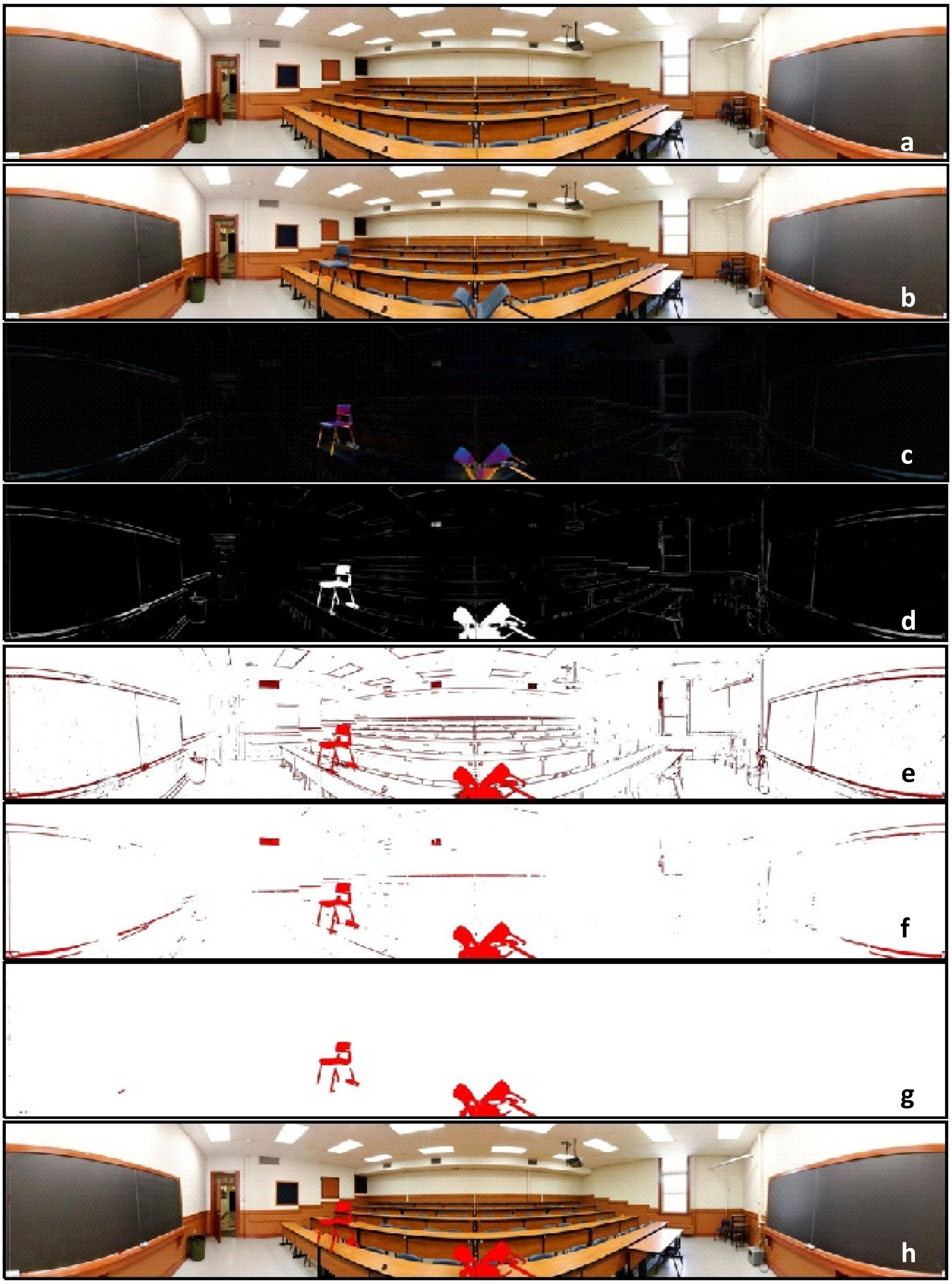

Figure 1: Classroom pilot study images: (a) Base state, (b) Objects moved, (c) Pixel intensity differencing, (d) Threshold of 35, (e) Change mask overlay, (f) Smoothing filter of 6 pixels, (g) Contraction/expansion filter of 5 pixels, (h) Final change mask overlaid

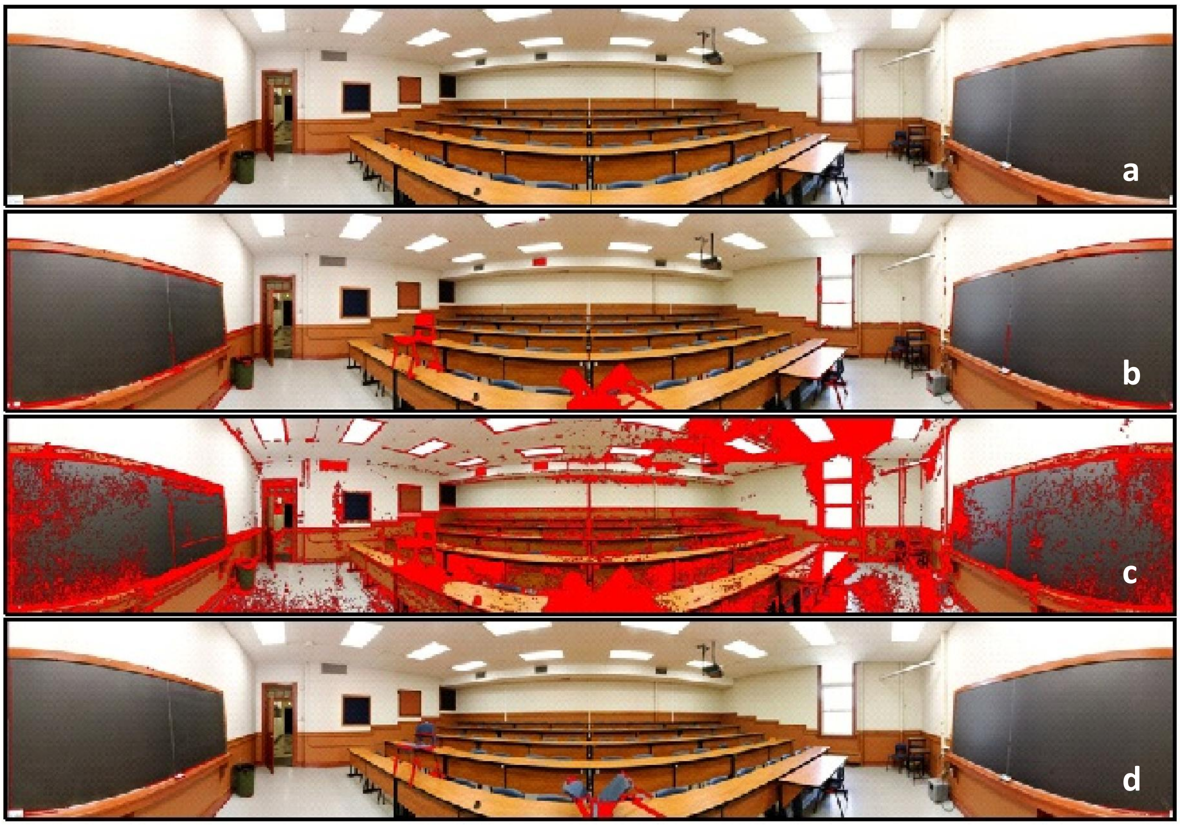

Figure 2: Threshold images: (a) Base state, (b) Balanced threshold of 35, (c) Low threshold of 5, (d) High threshold of 140

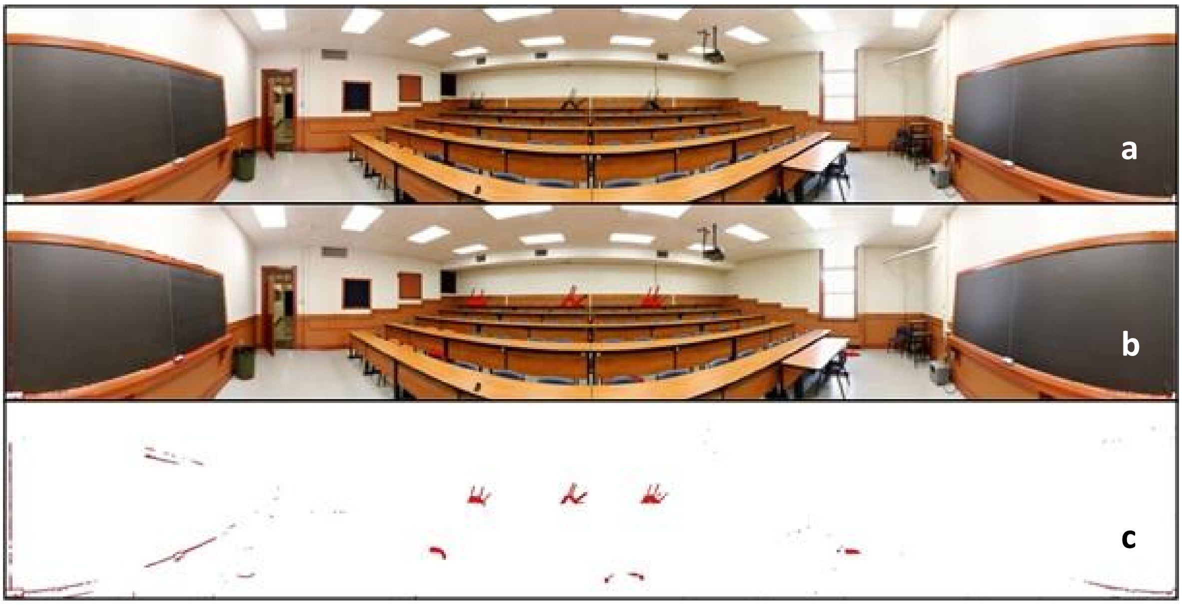

Figure 3: Distance images: (a) Far objects moved, (b) Final Change mask overlaid, (c) Change mask with contraction/expansion of 3 pixels

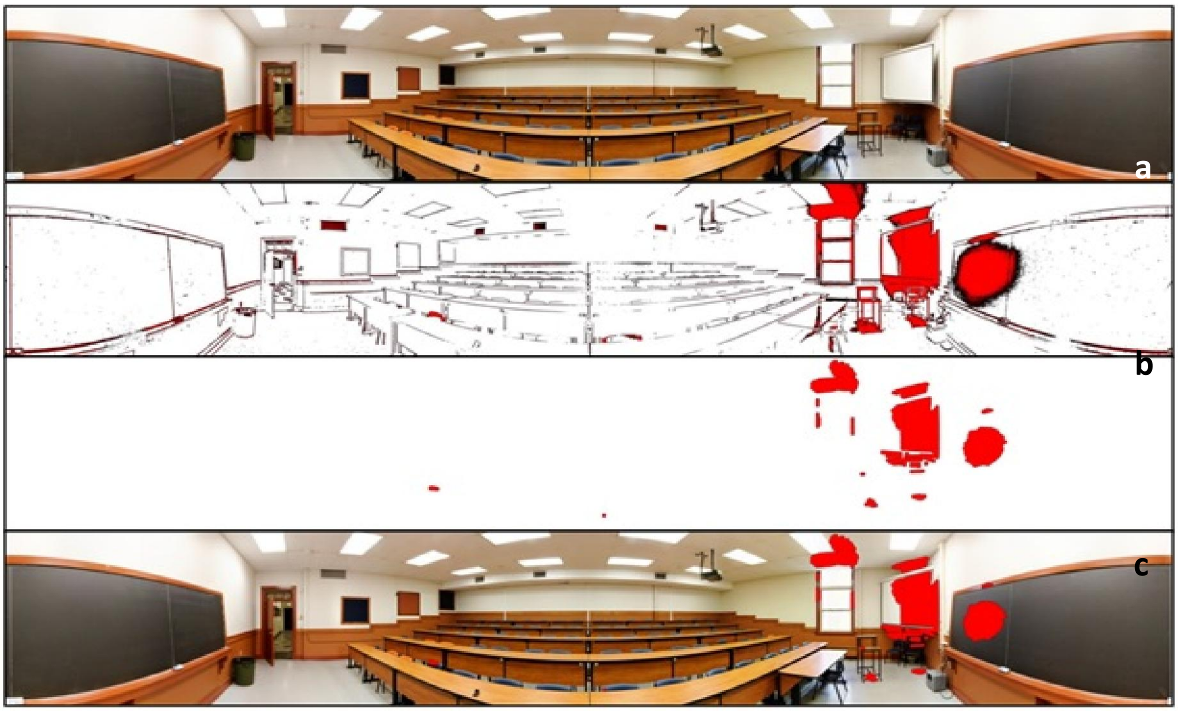

Figure 4: Similar color images: (a) Similar color objects moved, (b) Change mask, (c) Change mask with contraction/expansion of 20 pixels, (d) Final change mask overlaid

The images were captured over a period of 16 minutes which was enough time for shadow locations to change with the position of the sun. Lighting conditions also changed rapidly as cloud cover was sporadic. Although the camera remained in the same location for both images, alignment was necessary due to the rotating panoramic head which did not start at the same angle in each panorama. The techniques employed included histogram matching, a threshold of 110, and a contraction and expansion filter of 1 pixel. The before, after and change masks are shown in Figures 7(a), 7(b) and 7(c) respectively. Pixels detected in error range from 1 pixel wide to approximately 20 pixels wide. This is much larger than the objects being detected and therefore the contraction and expansion filters are not expected to perform well. This is apparent in the final change mask in Figure 7(c). A variable not originally considered which may have contributed to error in this test is wind. Error is more prominent in areas with foliage.

6 DIFFICULTIES WITH DIFFERENCING

Changing the location of the camera creates great difficulty when trying to detect change using differencing. Objects in the images no longer align. Errors will occur throughout the image where objects now overlap new objects. In the case presented below, the camera moved approximately three meters from right to left. Aligning the images is not as straightforward as simply sliding back to the right in Figure 8(b). Two types of errors occur when the camera moves which are not corrected by sliding the image; apparent object size and parallax. In Figure 8(b) the doorway is larger than Figure 8(a), and the projector screen on the right is smaller. Parallax is evident in many places. In the second image there is now more background visible behind the garbage can. The projector appears to have moved to the right of the room, apparent by its position relative to the corner of the room. Errors detected from changing camera location alone are presented in Figure 8(c).

7 CONCLUSION

Preliminary research on incorporating change detection in panoramas for documenting construction progress reveals many factors which make implementation challenging. A major concern is the requirement for the camera to remain in the same location for subsequent captures. Using multiple fixed cameras significantly increases the cost of implementing this technology and leaving cameras onsite would likely disrupt construction activities.

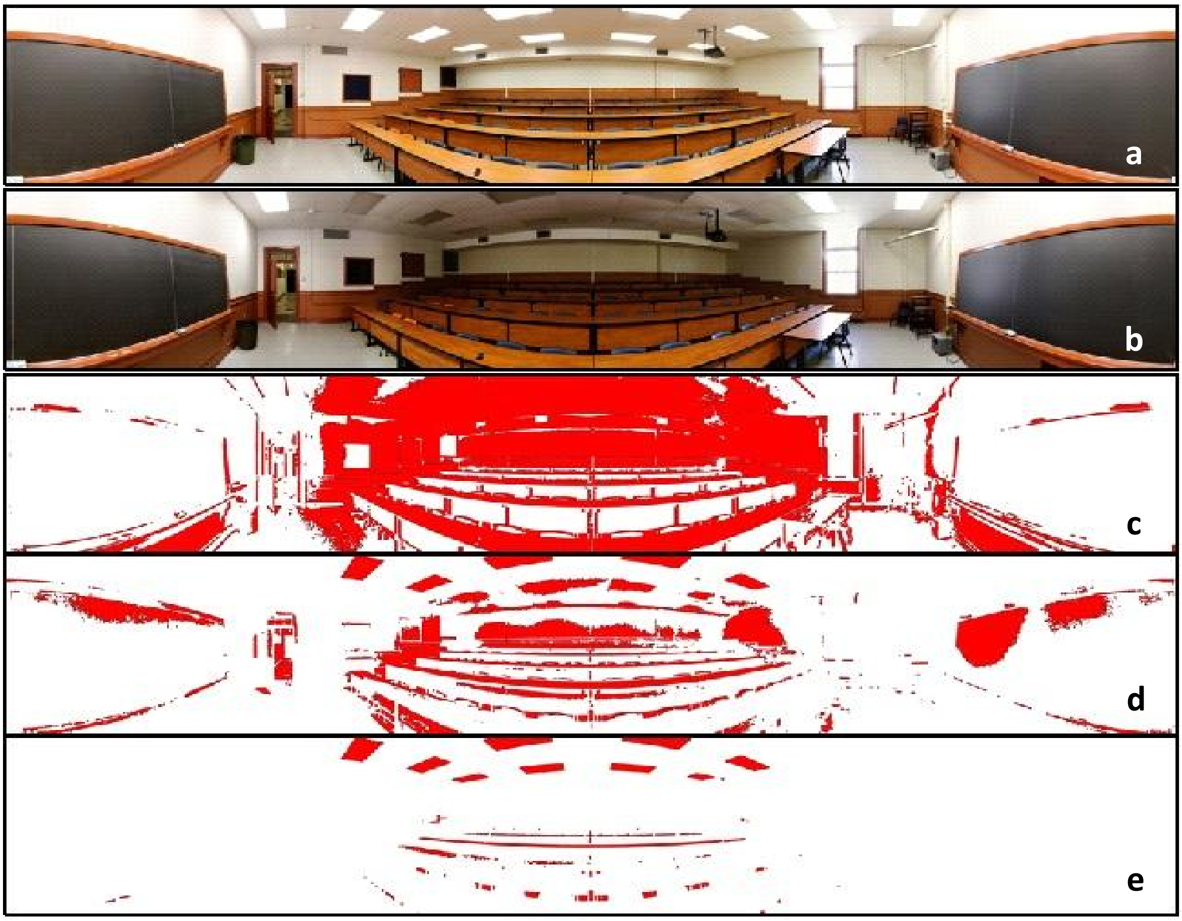

Figure 5: Light location: (a) Base state, (b) Lighting location change, (c) Change mask with threshold of 35, (d) Change mask with threshold of 70, (e) Change mask with histogram matching

Lighting conditions also pose problems as they can vary significantly as construction progresses. Histogram matching reduces errors caused by global variations in lighting however it is ineffective at correcting dramatic localized changes. Also, efforts to reduce these errors decrease the sensitivity of detection. These limitations make change detection by differencing impractical for use with panoramic site monitoring systems. It may be better suited to time lapse photography in which the camera does not change position. Table 2 shows a list of change detection challenges and corresponding solutions.

Table 2: Change detection challenges and solutions

Challenges	Solutions
Photography Variables	
Camera changed location	Camera must be fixed
Lack of detailed detected	Move camera closer to object
Objects not detected	Change color of object
Post-processing Variables	
Lighting condition changed	Histogram matching
Objects not detected	Adjust threshold
Errors of small area	Contraction/expansion filter, Smoothing filter
Images do not align	Image registration

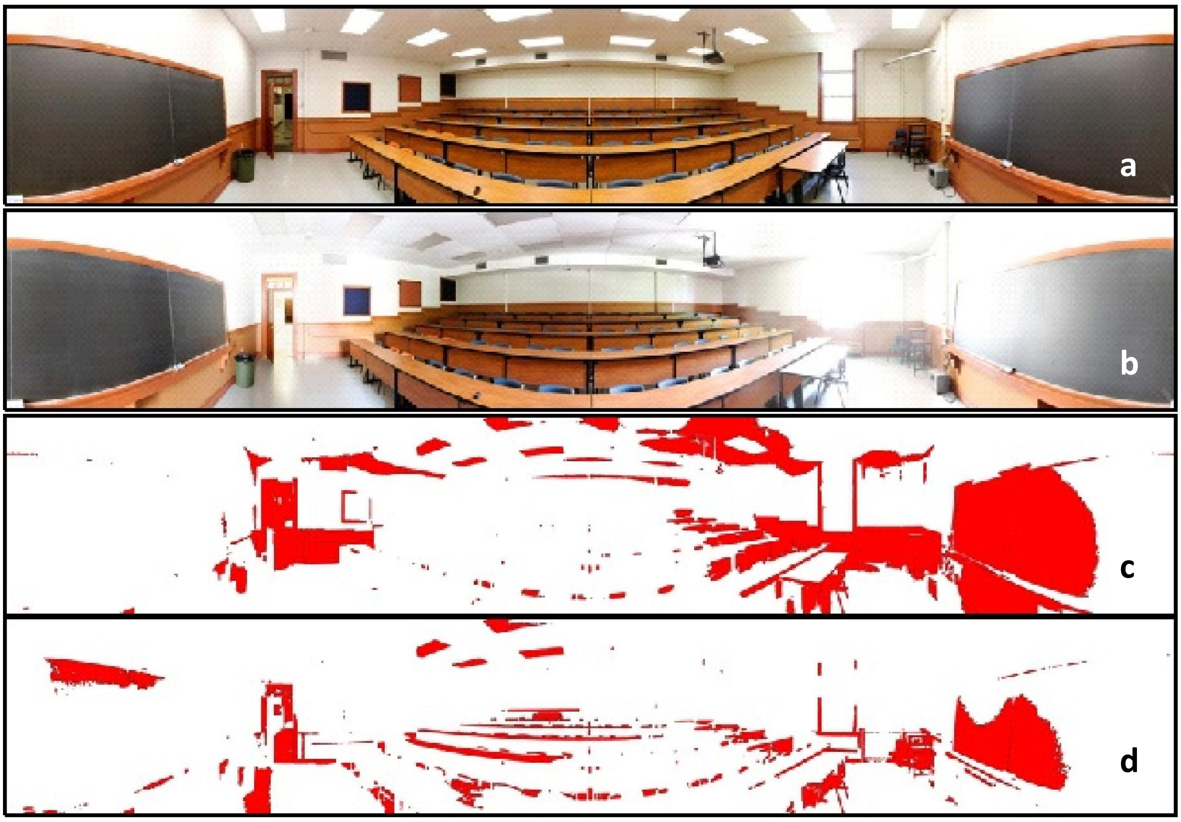

Figure 6: No artificial light: (a) Base state, (b) Lighting changed, (c) Change mask with threshold of 35, (d) Change mask with threshold of 70

Figure 7: On-site testing: (a) Base state, (b) Objects moved, (c) Final change mask

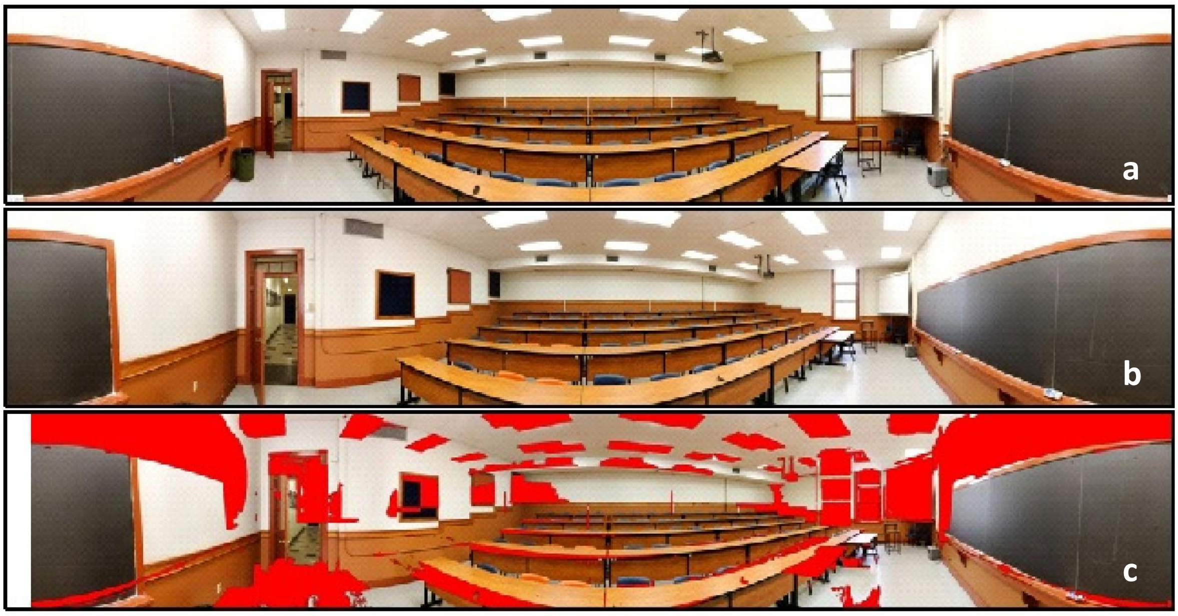

Figure 8: Differencing: (a) Base state, (b) Camera location change, (c) Final change mask overlaid

8 RECOMMENDATIONS

This research has explored techniques which expand the current status of panoramic monitoring systems through pixel based change detection in panoramas. While these techniques produce acceptable results they require a significant amount of input and judgment from the user. Future steps to improve this research include developing algorithms to determine appropriate settings for all inputs which will reduce the trial and error nature of the techniques. This will lead to an automated change detection process, eliminating much of the user input and workload. Research into computer vision technology and object based change detection is also an area of interest as it may allow changes in camera location between photography dates and be less prone to error caused by variations in lighting.

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