A METHOD OF CREATING GRAPHICAL THREE-DIMENSIONAL RECONSTRUCTIONS OF HIGH VOLTAGE DISCHARGE CHANNELS USING DIGITAL IMAGES

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Abstract: This paper describes a method used for graphically reconstructing three-dimensional flashover discharge channels within an interactive virtual environment. The system for reconstructing high voltage discharge channels is presented, with an example of the reconstruction process using tests from a 5.85 m floating object setup of switching impulse U_{50} tests. This work provides the possibility of studying photographed flashover events in the form of a reconstructed model with the ability to zoom, tilt and rotate the channel within a three-dimensional environment.

1 INTRODUCTION

Flashover is often a desired effect in high voltage testing, but in the case of flashover occurring in live, operating equipment, the resulting damage can be catastrophic. Burn marks, damaged insulation and carbon by-products are usually the only visual indication of failure due to flashover. Even if an operator is available to witness the failure, the naked eye may not be able to fully perceive the extent of damage, as the discharge channel of a flashover is fast and almost instantaneous with µs durations.

By obtaining a three-dimensional (3D) representation of a flashover discharge channel, the channel can be properly analysed in a three-dimensional visualised space. This paper will discuss the three-dimensional reconstruction of single-channelled flashover discharges from a large floating object setup, a total gap length (from high voltage electrode to earth electrode) of 5.85 m. An example will be presented throughout this paper, from the image acquisition to the completed reconstructed model.

2 BACKGROUND

Although it is not customary to photograph high voltage discharge channels in the laboratory, similar discharge channels are usually photographed in the form of lightning. With the development of more sophisticated camera technology, a move toward high speed cameras has opened up even more possibilities in researching the mechanisms behind these fast-occurring transients. In addition, there are obvious visual parallels that can be drawn between lightning and high voltage flashover channels. This paper makes use of only standard speed camera images of flashover channels to demonstrate a reconstruction procedure that can be extendable to high speed camera footage.

There is significant value in understanding the physical distribution of a high voltage discharge channel, as this is often an indication of weaknesses in equipment designs and understanding how the electric fields are affected in live-testing. The physical distribution of high voltage discharge channels is typically considered using photography of the discharge channel from a single perspective.

One photographic perspective also lacks the ability to fully grasp the spatial propagation of the channel, which highlights a need to develop a system that is capable of reconstructing a discharge channel within three-dimensional space.

3 SYSTEM OVERVIEW

A system was designed and developed to reconstruct high voltage discharges in three dimensions using photographic images coupled with the locations of cameras in relation to the test setup. An important feature of its design is the reusability of the system to different types of discharge channels, which specifically takes Boolean black and white images discharges as inputs. This system was previously tested using 0.83 m long single-channelled high voltage discharges in a small scale test [1], [2], and in a lightning environment using one image of a branched lightning discharge as a preliminary investigation [3]. Each of these tests proved to be successful in reconstructing a three-dimensional model from test images.

Figure 1 provides a block diagram representing each stage of the reconstruction process. This paper describes an overview of the modelling procedure; from obtaining photographs of the high voltage discharge channels, to creating the models in a three-dimensional interactive virtual environment.

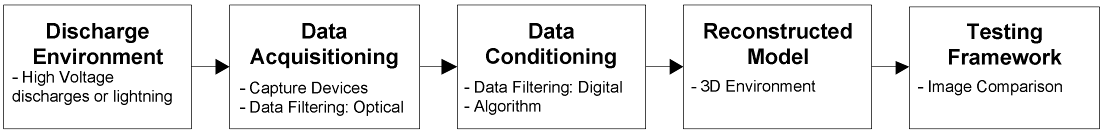


Figure 1: Overview of the system for the three-dimensional lightning reconstruction application.

3.1 Reconstruction Application

The reconstruction framework and algorithm was developed in C++ using a visualization toolkit library (VTK). The application framework accepts two or three image perspectives as inputs to the system. Two image inputs enable the reconstruction of single-channeled discharges, and three image inputs enable reconstruction of multiple channeled discharges.

3.1.1 Image Processing An image of a flashover often includes extra information that is not required in the reconstruction of the channel. The framework includes a number of built-in automated digital filters to eliminate this redundant information. These filters replace pixels that represent the discharge channel with white pixels (pixel value of 255), and negative space information as black pixels (pixel value of -255). Depending on the quality of the input images, manual image processing may be implemented to correctly categorise ambiguous grey pixels.

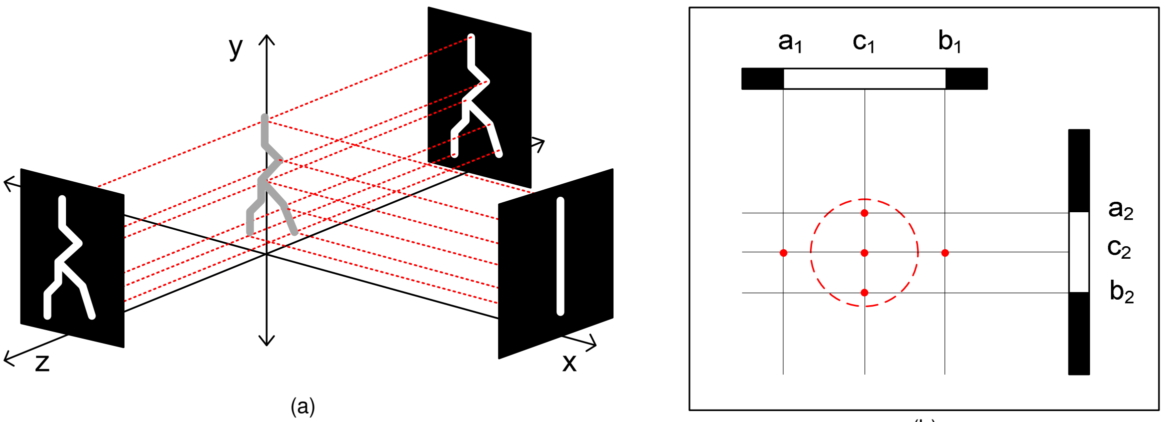
3.1.2 Reconstruction Algorithm The digitally processed images are placed in the three-dimensional virtual environment in corresponding position to original relative camera positions as demonstrated by Figure 2a for 90º camera separations. In this example, the simplest demonstrative sets of data are used; i.e. mirror images of the branched data, and a flat 90º angle. The reconstructed flashover discharge channel is centred about the y-axis (i.e. x = 0 and z = 0) in this virtual environment.

The modelling problem is three-dimensional and can be complicated if all the dimensions are tackled at once. Therefore, the modelling algorithm has been simplified to a series of two-dimensional geometric problems. For example, consider a single-channelled discharge channel that has two camera perspectives demonstrated in Figure 2b. Looking at the scenario from a bird's eye view, the first white pixel band at the top of each image extends three perpendicular normals from each image towards the y-axis. Each normal is extended from a specific point in the one-pixel high band of white pixels. The points are demonstrated in Figure 2b and listed below:

a. Leftmost white pixel
b. Rightmost white pixel in a continuous band
c. Middle position between point a. and b.

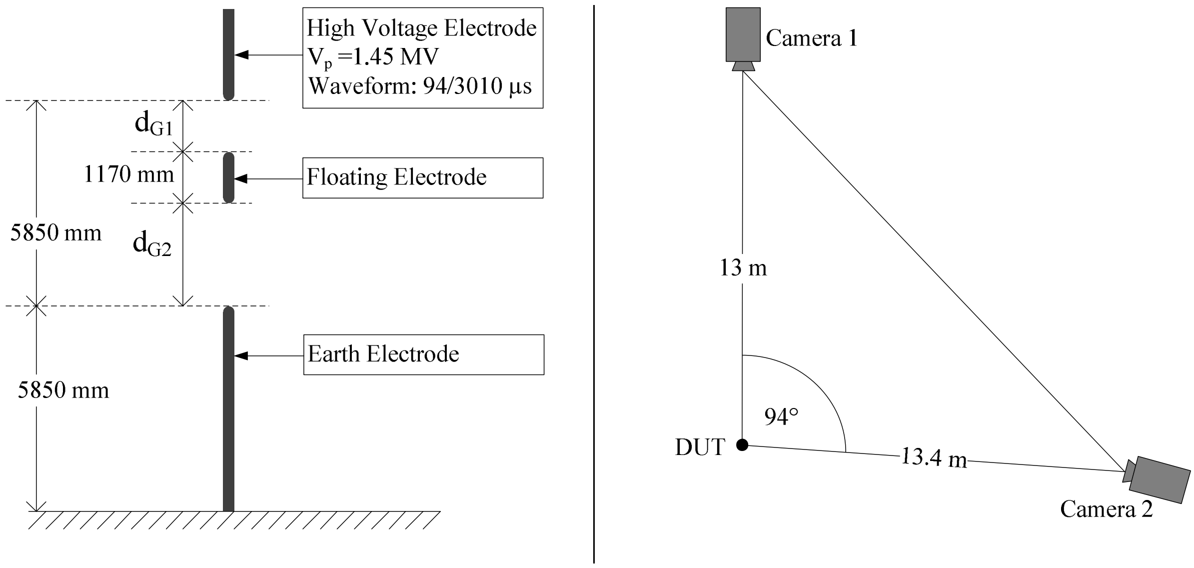
The middle normals of each image are compared for an intersection. If an intersection between the normals exists, a one-pixel high cylinder is created, The intersection points of the leftmost and rightmost white pixel positions are used to calculate the radius of the cylinder as demonstrated in Figure 2b. This process is repeated to produce a reconstructed model that is constructed by a series of stacked cylinders.

This method fails if the channel width is too thin (i.e. one or two pixels wide), and when the angle of separation between the perspectives is too small, i.e. less than 30º or too oblique (150º-210º).



(a) (b)

Figure 2: A graphical representation of the three-dimensional reconstruction algorithm which reduces the problem to a series of two-dimensional geometric solutions. (a) Processed lightning images placed in at positions of 90º-separations in a three-dimensional virtual environment with a simple representation of extended normals to reconstruct a channel. (b) Overhead two-dimensional perspective with relevant points in a data image extending geometric normals towards the y-axis.



(a) (b)

Figure 3: Physical laboratory setup (a) Floating object U_{50} setup with varying gap distances d_{G1} and d_{G2}. (b) Two camera setup, laterally separated by 94º in relation to the DUT (experimental setup).

Table 1: Gap configurations recorded during U_{50} tests of the floating object setup in Figure 3a.

Gap Configuration	d_{G1} (mm)	d_{G2} (mm)
1	1170	3510
2	1560	3120
3	1950	2730

4 EXPERIMENTAL SETUP

The experimental setup will discuss specifics of the gap configuration and the camera setup.

4.1 Discharge Environment

Image test datasets of flashovers were obtained from a floating object, double rod-to-rod gap configuration in air, with rounded tip electrodes. The gap configuration is illustrated by Figure 3a, where d_{G1} is the distance of the gap between the high voltage electrode and the floating object and d_{G2} is the distance of the gap between the lower portion of the floating object and the ground electrode.

A U_{50} test procedure was implemented to the setup using a 90/3010 µs switching impulse with an approximate peak voltage of 1.45 MV applied to the high voltage electrode at the top of the setup. Iterations of the gap configuration were obtained by varying the position of the floating electrode between the fixed high voltage and earth electrodes. Of the full range of U_{50} tests, three gap configurations were recorded, which are presented in Table 1.

4.2 Image Acquisition

Two camera perspectives were used during the U_{50} tests of the floating object setup. Figure 4a and 4b show the two perspectives of the same flashover of one gap configuration 1 breakdown (taken from Table 1). The cameras were placed approximately 13 m away from the test setup (DUT) with a lateral separation of 94º. Figure 3b) indicates the general floor plan with the camera positions in relation to the experimental setup.

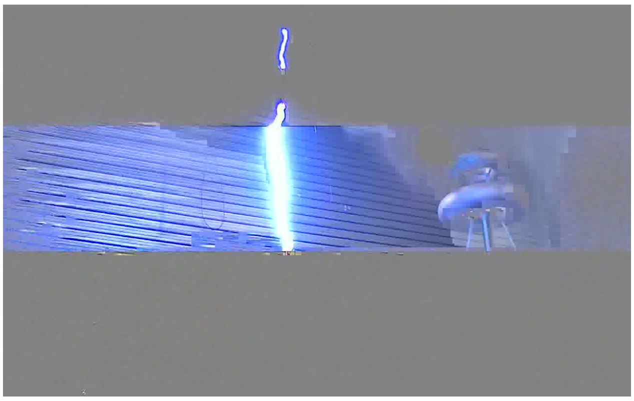
Identical surveillance cameras were used, which have several specific functions that allowed for automating the recording process, listed below:

1. 8-20 V input power
2. Trigger by motion detection
3. Pre-buffer
4. Local memory storage

Given the large input voltage range of the cameras, each camera was electrically isolated during the test runs, using small 12 V (5 Ah) lead acid batteries. The customisable motion detection functionality enabled the camera to trigger without any manual intervention. A one second pre-buffer was implemented to ensure information was not lost, and 3-second duration videos were stored on a local removable SD card.

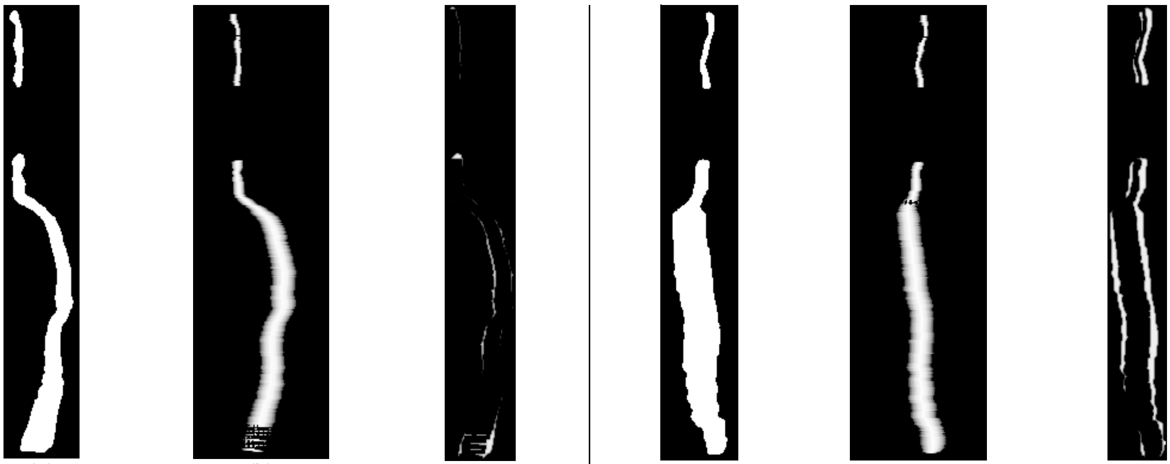
The cameras were operating at 15 frames per second with image dimensions of 1280 × 800. These settings produced videos with one or two (or none) frames with flashover image information.

(a) Camera 1 (0º)



(b) Camera 2 (94º)

Figure 4: Sample set of images of flashover occurring over a floating object with Gap Configuration 1 as presented in Table 1 for three-dimensional reconstruction.



(a) (b) (c)

(i) Perspective 1 (0º)

(a) (b) (c)

(ii) Perspective 2 (94º)

Figure 5: Reconstruction model input images and correlating images of outputs. (i) Perspective 1 relating to Camera 1 at an angular reference of 0º. (ii) Perspective 2 relating to Camera 2 at 94º of Camera 1. (a) Digitally filtered image. (b) Three-dimensional reconstruction in three-dimensional environment. (c) Test image presenting the difference between image (a) and (b).

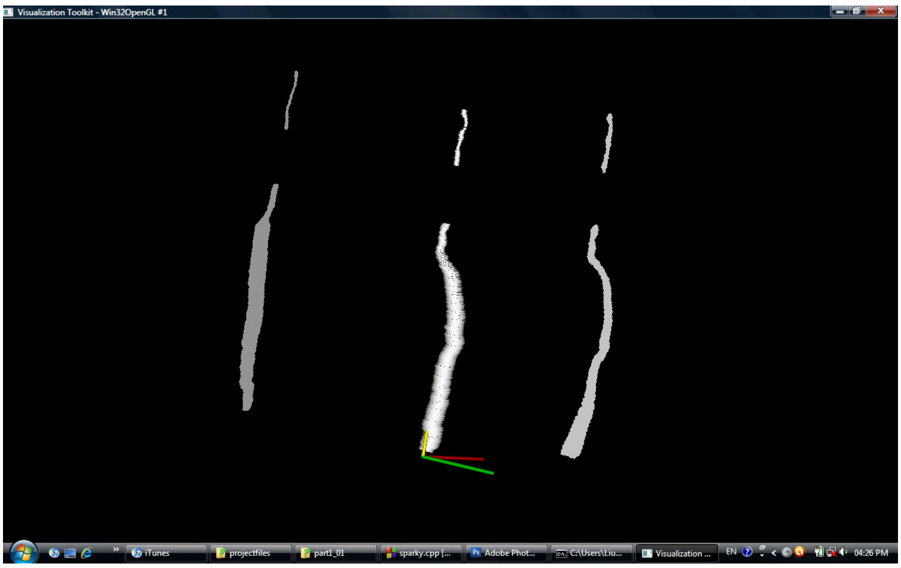


Figure 6: Three-dimensional model in the virtual interactive environment, flanked by image data on either side. Perspective 1 image place at 0º (right) Three-dimensional reconstruction (middle) Perspective 2 image place at 94º (left).

5 MODEL AND VIRTUAL ENVIRONMENT

The channel information is isolated from the original images through digital filtering, in Figure 5a – for perspective 1 and 2 (i and ii). The digital filtering process also required a manual scaling of images, to ensure that the correct comparative data is used. The three-dimensional model is constructed using the digitally filtered images and the resulting an image of three-dimensional model taken at the same corresponding angle to the original perspective for comparison, as demonstrated in Figure 5b.

Figure 6 illustrates a sample window of the interactive virtual environment, featuring the reconstructed flashover model demonstrated in Figure 5. The reconstructed model is placed in the centre of the setup, with a set of x-y-z axes at the base of the model. On either side of the model is the digitally filtered images (placed in respective positions to the original perspectives), of which normals were extended from in order to create the model.

6 TESTING

Visually, it is evident that the reconstructed model correctly follows the path of the flashover channel in the image. As the original flashover channel information can only be projected from the photographed information, the testing procedure primarily tests the accuracy of the reconstruction algorithm, by comparing input data to output data.

Figure 5c – for perspective 1 and 2 (i and ii) – demonstrates an image highlighting (with white pixels) the difference between the digitally filtered image and the image of the model in the corresponding perspective.

It can be seen that perspective 2 demonstrates a larger mismatch in pixels, than perspective 1. This is expected, since part of the original image is over-exposed due to the recording mechanics of CMOS camera chips. Since the reconstruction algorithm takes the average width of the channel from each of the images, it could be assumed that the reconstructed model is represented as thicker than it should be. This is also buffered by the fact that the photographed channel width is dependent on the exposure time of the CMOS sensors, which would vary for individual cameras operating on isolated circuits.

7 FUTURE WORK

The reconstruction of single-channelled flashover discharges does not demonstrate the full capability of the reconstruction system. Tests using simple discharge channels will be implemented in the future, which would include complex lightning channel structures.

Currently, there is a significant amount of manual modifications that are made in the digital filtering process, which is mostly represented by the manual scaling of images. Future work requires the implementation of an automated reconstruction system.

Furthermore, since current methods of testing only consider image mismatches, a more accurate and comprehensive testing framework needs to be implemented to quantify the error associated with the reconstruction algorithm – this will have a large effect on branched channel structures.

8 CONCLUSION

The algorithm has been shown to provide successful path reconstructions of single-channelled flashover discharge channels, for a floating object experimental setup. Further investigations include the three-dimensional reconstruction of branched channels and complex lightning channels. Several modifications need to be implemented to the current system for better automation and an accurate testing framework.

9 ACKNOWLEDGMENTS

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10 REFERENCES

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