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QUANTITATIVE SHAPE ESTIMATION OF HIROSHIMA A-BOMB MUSHROOM CLOUD FROM PHOTOS

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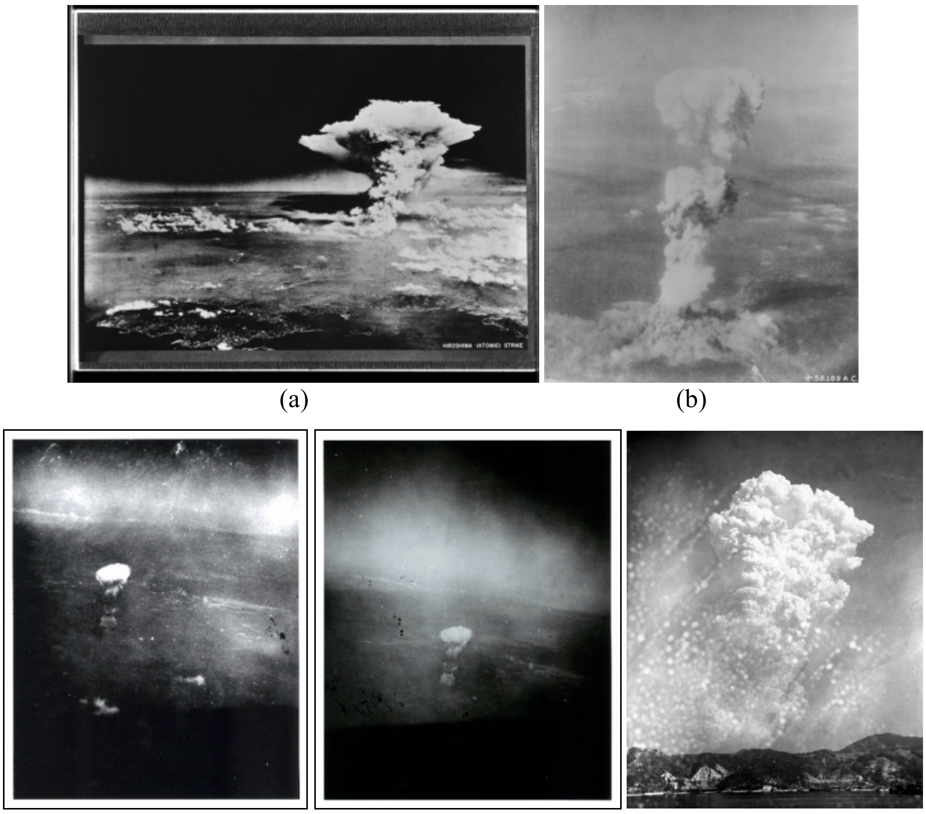
ABSTRACT

The estimated height of the mushroom cloud that formed after the A-bomb explosion at Hiroshima has been a controversial issue for many years. In this work, we have attempted to measure the cloud height from existing photos taken at the time from airplanes and from the ground using three types of metric cues. Our experimental results suggested that the height reached a maximum of about 16 km.

1. INTRODUCTION

In 1945, the atomic bomb dropped on Hiroshima caused extensive damage. To this day, many people continue to suffer from sequelae related to the event. The affected area has not been specified accurately. There are numerous radiation victims who have never received compensation for their injuries. A weather simulation of the rainfall patterns has been performed in the region where Black Rain fell from the mushroom cloud. In fact, the region estimated by the simulation is narrower than the actual affected area[1]. This discrepancy comes from an incorrect presumption of the mushroom cloud height. In this paper, we have estimated the height and width of the mushroom cloud using geometric camera calibration methods. Camera parameters such as the position and the focal length have been determined from the coastline or the horizon. Subsequently, we have approximated the shape of the mushroom cloud and have obtained the height and the width of the cloud.



(a) (b)

(c) (d) (e)

Figure 1. Photos used for analysis

2. TARGET PHOTOS FOR ANALYSIS

After the atomic bomb was dropped, many photos of the mushroom cloud were taken for various purposes. Several photos that exist to this day portray various cloud features. To perform a meaningful analysis using these photos, the precise location of the camera viewpoint is needed in each case. To estimate the point where each photo was taken, geographical features can be used as a means to find the specific locations. Among these features, we have used coastlines, horizontal lines and ridgelines of mountains as clues. There are a limited number of photos that contain sufficient information to analyze the dimensions of the mushroom cloud. The target photos for our analysis are listed as follows.

2.1. Photos in which coastlines appear

The images in which coastlines appear are shown in Fig. 1(a),(b). In these cases, the camera position can be estimated by calculating the relationship between the coastline in the photo and the coastline on the map or the aerial photo.

2.2. Photos taken with known altitude

These are images that have no clues specifying the location, yet the horizon is clearly indicated and the altitude is known, as shown in Fig. 1(c),(d). These photos were taken from the airplane that followed the bomber Enola Gay, which dropped the atomic bomb. Testimony about the altitude at the time of the photography was obtained from the photographer. From this testimony, the horizontal distance between the hypocenter and the airplane has been estimated.

2.3. Photos in which the mountain ridge appears

It is difficult to analyze photos taken from the ground because these contain few visible clues to use as a means to estimate the viewpoint. However, there exists an image of the event with a mountain ridge visible in the foreground, as shown in Fig. 1(e). It is possible to use the mountain ridge as a means of comparison to estimate the location of the photo.

3. VIEWPOINT ESTIMATON

In this section, we describe the procedure for estimating the viewpoint of the photo of the event. This piece of information is the first stage in estimating the shape of the mushroom cloud.

3.1. Viewpoint estimation by aligning the coastline

To estimate the cloud size using coastline images, we have acquired corresponding points on the coastline in the image and on the map as feature points. For these feature points, we have obtained the correspondence using the Iterative Closest Point (ICP) method[2]. Subsequently, we calculated the homography matrix[3] between corresponding feature points, as shown in Fig.

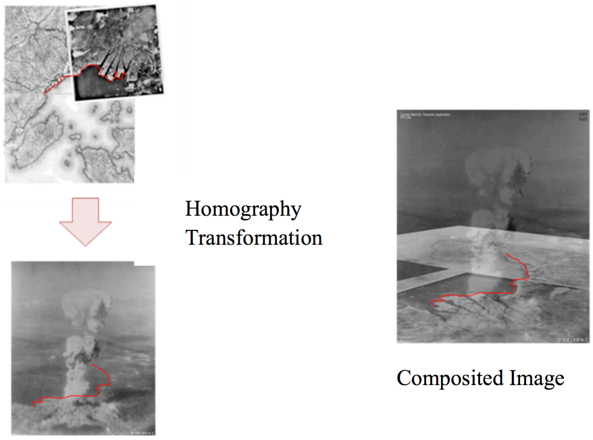


Figure 2. Viewpoint estimation using homography

2. We then estimated the position and the focal length of the camera used to take the photos.

3.2. Estimation of horizontal distance from photos of known altitude

As seen in Fig. 1 (c)(d), the coastline is not clearly visible, so the estimation method described above could not be used for these photos. Fortunately, Mr. Gackenbach, the photographer of the images in Fig. 1(c)(d), gave us the following testimony; 1)The photos were taken approximately one minute after the explosion, 2) The altitude was about 30,000 feet (~9.144 km), 3) The camera used for photo was an "Agfa 620". The last testimony determines the field of view of the used camera. Though it is difficult to estimate camera viewpoints from available information, we can estimate the horizontal distance from the hypocenter. More specifically, we can estimate the distance based on information about the camera's focal length, the location of the horizon, the location of the root of the cloud, and the altitude. From this information, we have estimated the horizontal distance from the hypocenter by minimizing the following equation,

$$\arg\min_{v} \left| \frac{(\mathbf{l}\times\mathbf{r})\cdot(\mathbf{e}-\mathbf{v})}{\|\mathbf{l}\times\mathbf{r}\|} - R \right| \qquad (1)$$

where v is the position of the viewpoint, l is the vector to the left point of the horizon, r is the vector to the right point of the horizon, e is the center of the earth, and R is the radius of the earth. Figure 3 summarizes the estimation procedure.

3.3. Estimation using the viewpoint location and the mountain ridge

The image in Fig. 1(e) contains no information about the coastline or the horizon. However, the photo has a distinctive landscape near the coast and a mountain ridge that can be used to determine the location of the photo. An image of the present coastal landscape in the

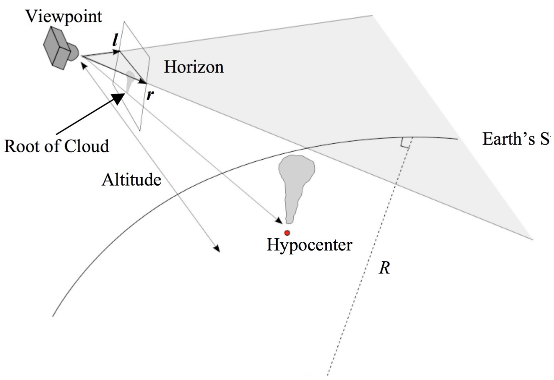


Figure 3. Estimation of the viewpoint for the photo in which the horizon appears

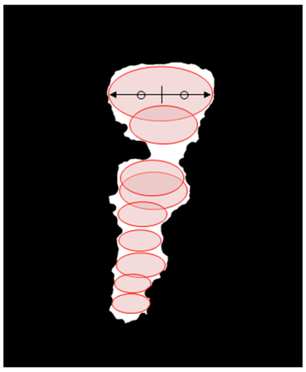


Figure 4. Ellipsoids fitted in the cloud region.

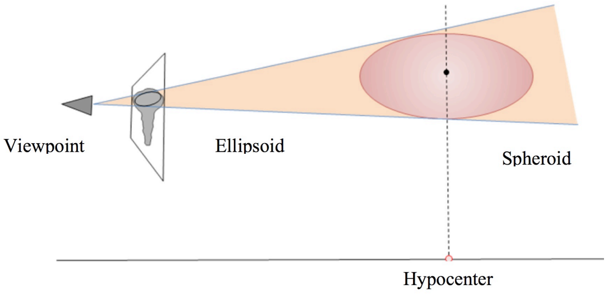


Figure 5. Estimation of the size of spheroids.

direction of the hypocenter, obtained from the Japan Coast Guard Academy in Kure, is sufficiently similar to the photo of the event. We have compared these images and are convinced that the photo of the cloud was taken from the Kure Japan Coast Guard Academy, where the Kure Naval Arsenal was located at that time. In addition, we obtained information about the camera. This was a Leica with Elmar F3.5 lens of focal length 50 mm; the film size was 24 × 36 mm.

4. SHAPE ESTIMATION OF MUSHROOM CLOUD

In this section, we describe a method for estimating the shape of the cloud, including its height and width, based on the estimated viewpoints. Typically, to obtain a three-dimensional shape, reconstruction techniques require multiple images[4]. Contrary, in our case, the shape of the mushroom cloud must be obtained from just one image, we have used a technique involving multiple spheroids and have subsequently determined the height and width.

4.1. Approximation of the area of the cloud

We have extracted an approximate cloud image by fitting ellipsoids in the zone of the cloud. As shown in Fig. 4, we have fitted ellipsoids in various regions of the cloud for regions above a certain threshold in diameter. The procedure is as follows.

1) Determine the ellipsoid containing the largest area that is not enclosed in other ellipsoids.
2) Remove the ellipsoid area from the object region.
3) Repeat the procedure until the area not included in the ellipsoid is below the threshold.

4.2. Estimation of the 3-D shape of the cloud

We have estimated the size and location of spheroids in 3-D space corresponding to the ellipsoids that were obtained in 2-D image. We have assumed that the spheroids are aligned on a frontoparallel plane placed at hypocenter as shown in Fig. 5.

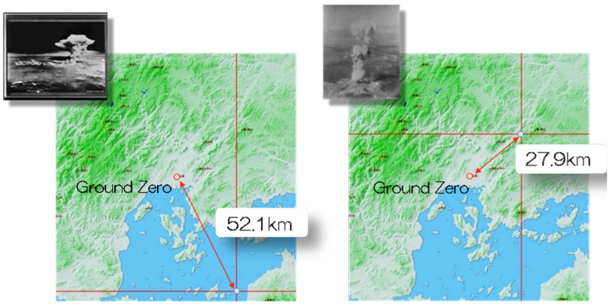
5. ANALYSIS RESULTS

In this section, we discuss our results. First, the results of the estimated viewpoints obtained from the photos are presented. Then, we show the results of the shape estimation of the mushroom cloud, including the height and the width of the cloud.

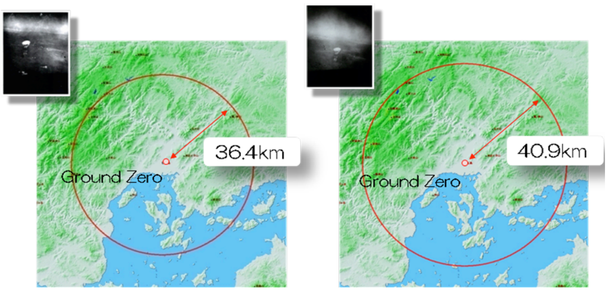
5.1. Viewpoint estimation results

First, we estimated the position and focal length for the images containing coastlines by aligning the photo and the maps. Largely because of the age and quality of these photos, the coastlines are not clear, so it is difficult to extract the coastlines automatically by using techniques such as segmentation or edge detection. Therefore, we have extracted the coastlines by visual inspection. Coastlines in the photos and maps are aligned using the ICP method and have estimated the viewpoint and the focal length. The locations of the viewpoints are depicted in Fig. 6 as the point where the red lines intersect. The altitudes of the viewpoint are 8.6km and 8.1km respectively.

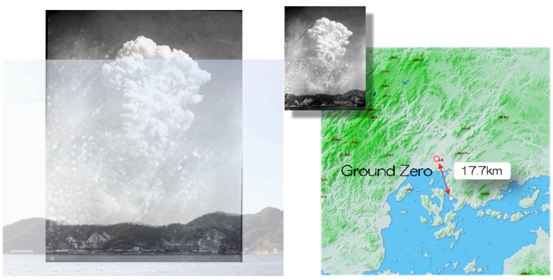
Using the geometric constraints given by the known altitude, we present the estimates obtained from photos shown in Fig. 1 (c)(d). From the position of the cloud base and the height of the horizontal line on the image, we have estimated the horizontal distance from the hypocenter. These results are shown in Fig. 7. Because



Fgiure 6. Estimated viewpoints of image (a) and (b).



Fgiure 7. Estimated distance of image (c) and (d).



Fgiure 8. Estimated viewpoint of image (e).

it is not possible to obtain exact viewpoints, the distance from the hypocenter is represented.

The last result of viewpoint estimation is based on the mountain ridges shown in Fig. 1(e). Fig. 8 shows a composite of the image of the event and the recent photo taken from Kure. As is evident in the picture, an adequate superposition of the landscapes has been obtained. Fig. 8 also shows the location and the distance from the hypocenter on a map.

5.2. Estimation of the shape of clouds

Using the focal length and the viewpoint, we have obtained a three-dimensional shape of the clouds. The height and the width were then estimated using this three-dimensional shape. In addition, we have divided the three-dimensional space into voxels and produced the corresponding surfaces using the Marching Cubes method[5]. We have divided an area of 50 × 50 km^2 around the hypocenter into voxels of size 0.1 km.

The results of the synthesis for the reconstruction of the shape of the cloud in Fig. 1 are shown in Figs. 9.

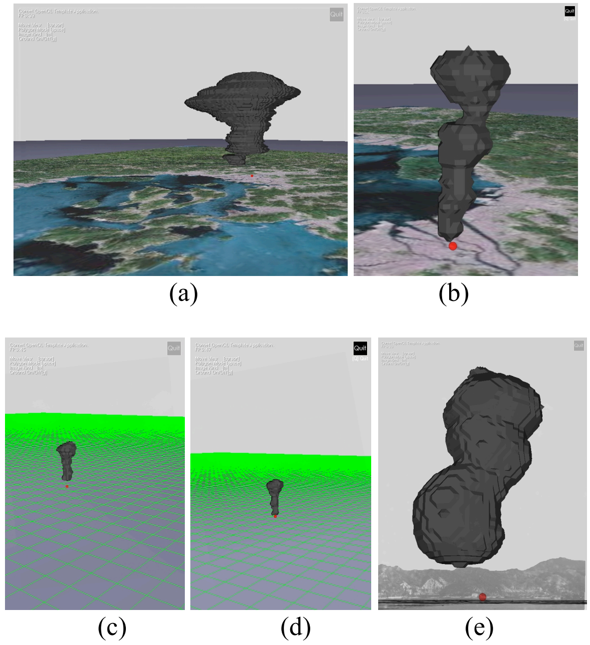


Figure 9. Shape of reconstructed clouds

Table 1. Summary of the estimation results

Photo	(d)	(c)	(b)	(e)	(a)
Height[km]	4.5	4.9	7.8	11.6	15.7
Width[km]	2.1	2.2	3.1	5.6	15.5
Distance[km]	40.9	36.4	27.9	17.7	52.1
Altitude[km]	9.1	9.1	8.1	0.0	8.6

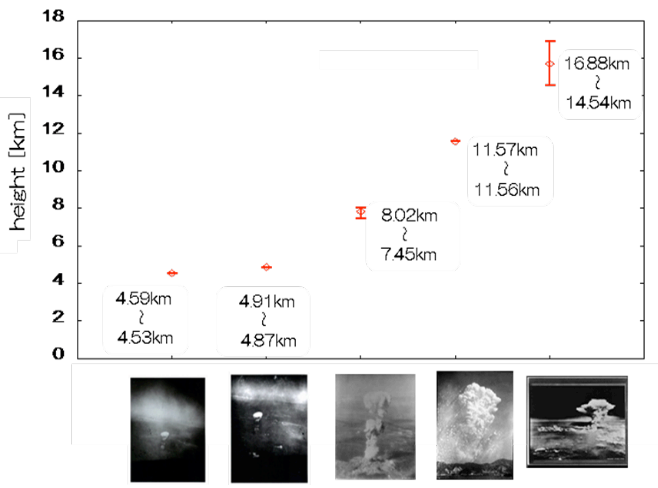


Figure 10. Summary of the 95% confidence level of the estimated heights

The approximated values for the cloud height and width are summarized in Table 1. The height of the cloud in Fig. 1(a) is estimated to be about 16 km. This largely exceeds the 8 km that was previously assumed. For the photos in Fig. 1(c)(d), the height is estimated to be about 5 km, much less than the results for the images containing the coastline. Assuming that the height of the mushroom cloud increases in monotonically, these images are of the mushroom cloud taken soon after the atomic bomb was released. Testimony exists that the mushroom cloud was initially one volume and then separated into two parts. However, as seen in these images, it is clear that this cloud is only one volume and the photos were taken just after the bombing.

Finally, we briefly mention measurement errors. Generally speaking, the estimated values include some errors. However, it is difficult to evaluate these errors because there are no true values. We evaluate the range of the estimated values by adding Gaussian noise to all feature points for the estimation. Figure 10 summarizes 95% confidence levels of the estimated heights. Since the height of the mushroom cloud grew monotonically, estimated height of each photograph indicates the chronological sequence of shooting time. The order corresponds to the known situations and testimonies of photographers.

6. CONCLUSION

In this paper, we have estimated the shape of the mushroom cloud that formed after the atomic bomb was dropped on Hiroshima in 1945 and have estimated the height of the cloud. We began by classifying the images of the mushroom cloud by their characteristics. We then estimated the locations where the photos were taken. For images with obvious coastlines, the photo viewpoints were estimated by performing an alignment of coastlines between the photos and maps. For photos with information about the altitude, obtained from the testimony of the photographer, we estimated the horizontal distance from the hypocenter from the set of constraints based on the testimonies and horizontal lines on the photo. For the image showing a mountain ridge in front of the cloud, we estimated the location of the viewing point by experimenting with photos taken at locations with a similar view of the mountain ridge. Using the estimated viewpoints, we approximated the three-dimensional shape of the mushroom cloud using spheroids by first finding ellipsoids in two-dimensional space and then projecting the ellipsoids onto the plane corresponding to the three dimensional spheroids. In addition, we divided the spheroids into a set of voxels, producing surfaces using the Marching Cubes method. Our experimental results have suggested that the height was at a maximum about 16 km. This largely exceeds the 8 km that was previously assumed.

7. REFERENCES

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