Disaster Monitoring in Urban and Remote Areas using Satellite Stereo Images: A Depth Estimation Approach

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***Abstract*—Disaster can occur any time either it is natural or human made. Urban areas are congested and highly populated in big cities. Any kind of natural disaster like earthquake or flood can damage the whole city or partially, depending upon the intensity. To enhance the rescue activities and saving lives; disaster monitoring and management plays a critical role. Many techniques are used these days to monitor and identify the intensity of damage e.g., aerial view of city, SAR, LiDAR, site survey or acquiring the satellite images. Remote sensing to monitor natural disasters has been proven useful for detection of earthquakes, land sliding, flooding, wildfire and volcanic activity. In our paper, we have proposed a method to monitor the disaster using satellite stereo images which can detect and measure the intensity of damage. For preliminary study, we have acquired the satellite images from Quick bird. Depth estimation algorithm on stereo images produces good results to monitor the urban and remote areas infrastructure as compared to the traditional methods like video surveillance.**

***Index Terms*—Disaster Monitoring, Satellite stereo images, Depth estimation**

I. Introduction

Remote sensing for understanding the geophysical phenomena underlying natural disasters has been widely used from past two decades. Integrating the geospatial information with the demographic data minimizes the risk for damages and also improves the disaster response to the affected areas and people.

The use of remote sensing has become more common in natural disaster and hazards domain. It became possible with the increase use of geospatial technologies which provide up-to-date imaging to the public and monitoring agencies. As the technology is improving day by day, the expectations have increased for real time monitoring and acquiring the visual images when any kind of natural disaster occurred [1]. Satellite technology improvement and availability make possible these expectations.

Remote sensing has been proved useful for a different kind of applications which includes detection of earthquakes, land sliding, volcanic activity, floods, and wildfire in jungles and damages produce by these hazards.

Disaster management includes four phases i.e., reduction, readiness, response and recovery [2]. Remote sensing plays a vital role in all these four phases. Different types of remote sensing techniques and methods are used and reported in literature for disaster and crises management.

In modern era, developments in satellite systems and image processing techniques can help to manage the natural disasters and crisis situations due to natural hazards. Different international coordination bodies were formed to tackle the situation in case of natural disasters e.g., Disaster Management support Group (GMSG) of International Committee on Earth observing satellites is one example. German aerospace center (DLR) also formed a center for satellite based crisis information (ZKI). This center collects and facilitates the national and international natural disaster situations [3].

Use of satellite images can be helpful and faster than other methods for hazard monitoring and detection. Weather satellites are most commonly used to address this issue. However, many other orbiting and geostationary satellite services are available which cover all the world on small time scales .The image acquisition from these satellites are cheaper or some time free available. Spatial resolution of the satellite image plays an important role in deciding whether a particular sensor data is capable for detecting natural hazard.

Urban areas are highly crowded and congested. Any natural hazard can affect a large number of people and can destroy the major infrastructures. Rapid response is the major concern in case of urban areas to safeguard and run the relief campaign for the people in that area. In response and recovery phase, only the fast up-to-date and accurate image analysis can help in better assessment of disaster and also particular in the remote areas where there is no easy access to the affected areas.

It is hard to make decision or understand the raw satellite images by non-satellite expert user to make any decision or start any kind of rescue and relief operation.it always takes a very careful processing of data, analysis, mapping, and interpretation process to generate the required disaster maps, reports based on these maps, or statistical data which can be further read and understood by non-satellite expert users [3, 4]. Therefore, it is desirable to have the good image analysis to generate the results which can be understood by crises management committees.

In our paper, we have proposed the image processing technique used for disaster management based upon the satellite imagery especially on stereo images. Different

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satellites can produce different kind of imaging e.g., either it is panchromatic or multispectral images. We have acquired the stereo images from Quick bird satellite for urban as well as remote areas.

Section II describes the related work and different imaging methods available. Section III gives the details of the proposed method and framework. Section IV gives the results and in section V we have summarized the paper.

II. Background & Imaging Methods

Space based approaches play a major role in all stages of a disaster. Earth observation satellites and meteorological satellites are an essential tool for gathering the information required to reduce the human and economic losses due to any kind of disaster either it is natural or human made [5]. Airborne stereo images have very high accuracy but expensive and limited access. Also it suffers from small coverage areas. On the other hand, space borne satellite images have lower accuracy but the data acquisition is very quick and can almost any location or area on the Earth. The cost for space borne imagery is less expensive than airborne imagery [6] [7].

A. Satellite Stereo Imagery

Stereovision is able to get the depth map of any scenery. It uses two stereo images acquired from two cameras to generate the disparity maps which can be simply transferred into depth maps. For real time robust application, reliability of depth maps and their computational cost of algorithms are the main key factors. Figure 1 shows how the satellite stereo images are acquired.

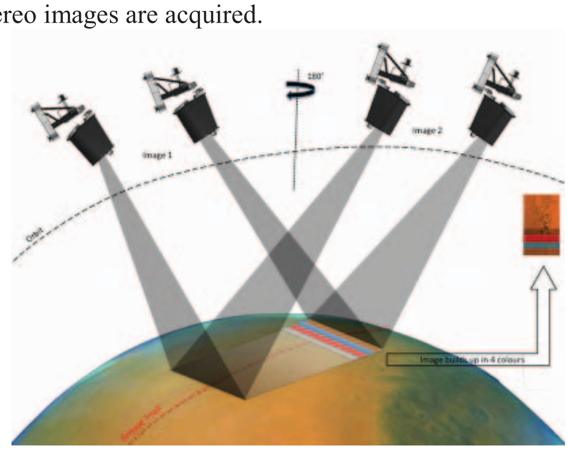

Figure 1. Satellite Stereo Image Acquisition [8]

B. 3D Building Reconstruction

3D building reconstruction and derived information from it can be used in different areas such as urban city planning, disaster management and navigation systems. 3D building reconstruction can be done using various imaging like aerial images, satellite images, LiDAR, Digital elevation model (DEM), Geospatial information system (GIS) maps. Satellite images and aerial images are the major imaging approach used for 3D reconstruction [9].

Two common approaches normally followed for this purpose i.e., model based and image based. 3-D coordinates of the object present in space can be calculated by finding the common or conjugate points of the two overlapping images.

C. Depth Estimation

Depth map of any scene is normally represented by a gray scale image and the intensity of pixel shows the depth. The pixel which is further away is represented by the lower the intensity value and the pixels which are very close are represented by very bright. The very far pixels are completely black.

III. Methodology

A. Data Acquisition

Geometrically corrected stereo Quick bird scene was used and data has been acquired for urban areas as well as from the remote areas. The data set consist of 1-m panchromatic and 4-m multispectral bands. The acquired image size is 500x700 pixels. Both panchromatic and multispectral images have been acquired.

B. Proposed framework

The acquired data is first preprocessed and cropped. The two stereo images are then used to calculate the disparity maps. These disparity maps are then further used to find the depth via the depth estimation algorithm. The depth maps then can be compared with the previously recorded satellite data to find the damage occurred by the natural hazards. Figure 2 shows the block diagram of framework that how we can get the desired information by using disparity maps and depth estimation technique.

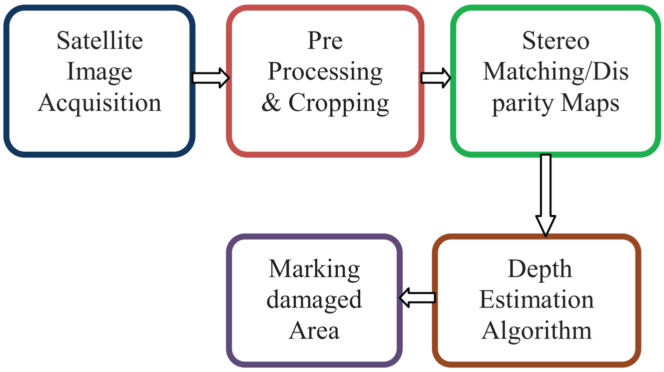

Figure 2. Proposed framework for disaster monitoring

C. Depth Map Generation Algorithm for Disparity Maps

When two cameras left and right i.e., C_L and C_R separated by a distance Δx as shown in Figure 3. I_L and I_R are the centres of the two images on right and left image planes. Consider a point $P(x_o, y_o, z_o)$ and its projection via point

P_L and P_R on both planes. By geometry, we can deduce the equation (1) and equation (2) [10].

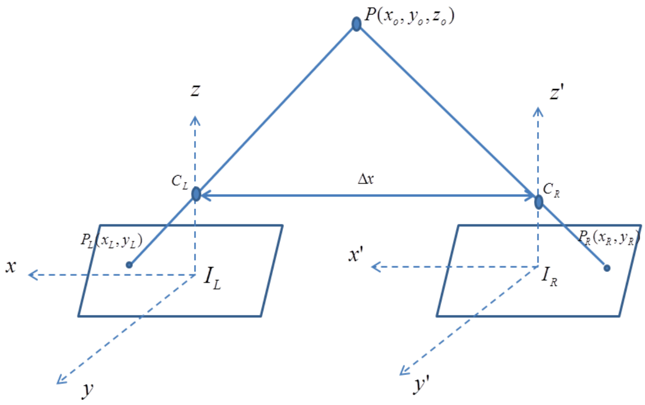

Figure 3. Lateral Stereo Camera Model [10]

$$\frac{x_o}{x_L} = \frac{y_o}{y_L} = \frac{\lambda - z_o}{\lambda} \quad (1)$$

$$\frac{x_o + \Delta x}{x_R + \Delta x} = \frac{y_o}{y_R} = \frac{\lambda - z_o}{\lambda} \quad (2)$$

By Solving equation (1) and (2), we get the unknown depth z_0.

$$z_o = \lambda + \frac{\lambda.\Delta x}{x_L - (x_R + \Delta x)} \quad (3)$$

Where the term $x_L - (x_R + \Delta x)$ is known as disparity '*d*'. First Energy matrix for every disparity is constructed and error energy can be calculated by equation (4).

$$E(u,v,d) = \frac{1}{3mn} \sum_{x=u}^{u+n} \sum_{y=v}^{v+m} \sum_{t=1}^{3} \left(I_{mL}(x+d, y+d, t) - I_{mR}(x+d, y, t)\right)^2 \quad (1)$$

Where I_{mL} and I_{mR} are left and right images and *d* is the disparity and *E (u,v,d)* is the error energy. For *m* x *n* window size, the average filter is defined by equation (5) [11].

$$\bar{E}(u,v,d) = \frac{1}{mn} \sum_{u=n}^{u+n} \sum_{v=m}^{v+m} E(u,v,d) \quad (5)$$

For every pixel *(u,v),* we can find the minimum $\bar{E}(u,v,d)$ and we can assign its disparity index to the *d(u,v)* which is also disparity.

$$d(u,v) \leftarrow Min\{E(u,v,d)\} \quad (6)$$

The reliability R_d of the disparity map is defined by taking the mean value of error energy of disparity maps (E). It can be represented by equation 7.

$$R_d = \frac{1}{Mean(E_d - \{p_e\})} = \frac{1}{W_d} \left(\sum_{(u,v)-\{E_d(u,v)=p_e\}}^{n,m} E_d(u,v) \right)^{-1} \quad (7)$$

Where p_e is defined as 'no-estimated' state. Error energy of disparity map can be found by equation (8)

$$E_d(u,v) = \frac{1}{3mn} \sum_{x=u}^{u+n} \sum_{y=v}^{v+m} \sum_{t=1}^{3} \left(I_{mL}(x+d, y+d(u,v), t) - I_{mR}(x+d, y, t)\right)^2 \quad (8)$$

Due to object occultation in some images, disparity maps can have some inaccurate disparity estimations for few points around the object boundaries. These unreliable disparities can be observed by seeing the high error energy present in E_d. The reliability in disparity map *d(u,v)* can be increased by introducing the threshold mechanism as given in equation (9).This will filter some unreliability in disparity estimation.

$$\bar{d}(u,v) = \begin{cases} d(u,v) & E_d(u,v) \le p_e \\ 0 & E_d(u,v) \ge p_e \end{cases} \quad (9)$$

Now $\bar{d}(u,v)$ will give more better version of *d(u,v)*. By setting the disparity to 0 in equation (10) known as non-estimated state and the values of $E_d(u,v)$ equal to 0 are excluded for calculation of R_d.

$$\bar{E}(u,v) = \begin{cases} E_d(u,v) & E_d(u,v) \le p_e \\ 0 & E_d(u,v) \ge p_e \end{cases} \quad (10)$$

By using this algorithm, we can estimate the depth of the building and it can be compared with the previously acquired images before any natural hazard. It is clear that satellite imagery based information alone does not enough to produce a fruitful analysis and results of a given catastrophe. Experiences and data gathered from relief organizations during their work show that it is desirable to merge or fuse the satellite based data with additional data to present it in a proper geospatial context. Therefore, in addition to the expert knowledge in image analysis, it is an equally important to generate the comprehensive and user friendly maps. To do this, reference data sets which contain the name of places, road details and connectivity, rivers, critical infrastructure and topographic information are required.

IV. RESULTS

By applying our method on stereo images acquired from QuickBird satellite, we have generated the disparity maps with variation of disparity index d_{max} from 20 to 40. Figure 4 and 5 shows the left and right stereo images of the urban area. Figure 6 shows the disparity map with 20 and Figure 7 shows the disparity map with 40.

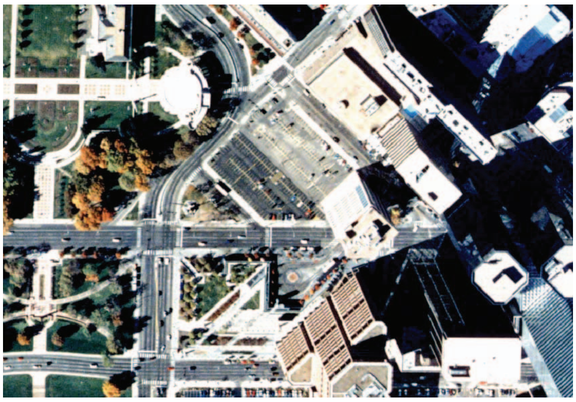

Figure 4. Acquired QuickBird Satellite Left Stereo Image (Urban Areas)

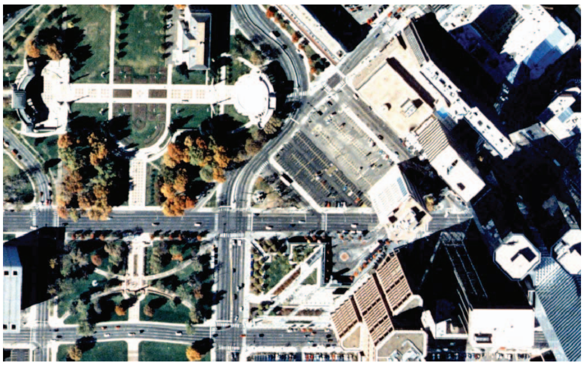

Figure 5. Acquired QuickBird Satellite right Stereo Image (Urban Areas)

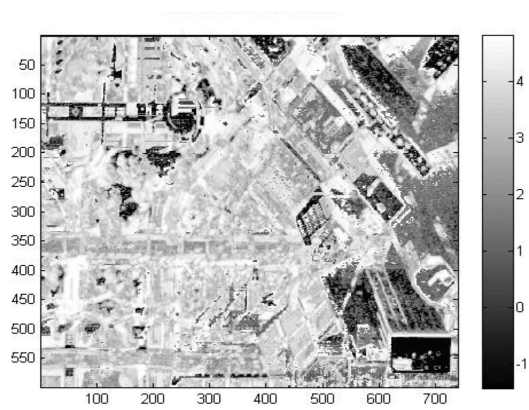

Figure 6. Disparity map of urban stereo images ($dmax$ =20)

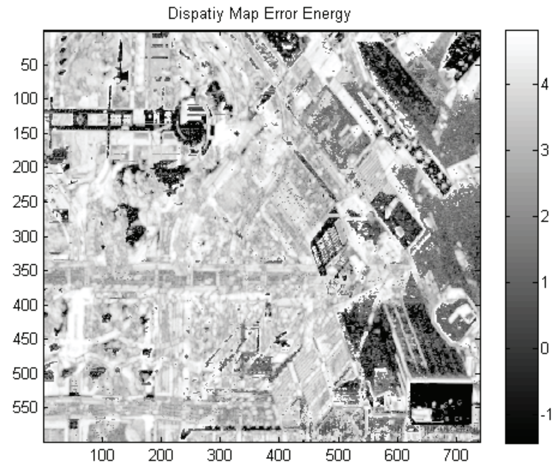

Figure 7. Disparity map of urban stereo images ($dmax$ =40)

In the second case, we have taken some localized area structure from the city .Figure 8 and Figure 9 shows the left and right panchromatic images of a football stadium. Figure 10 shows the disparity map.

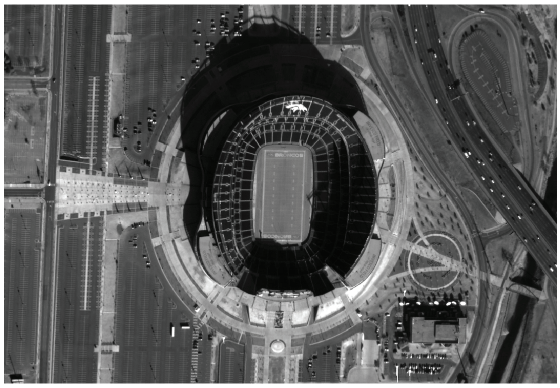

Figure 8. Localized urban area (QuickBird Panchromatic Image-Left)

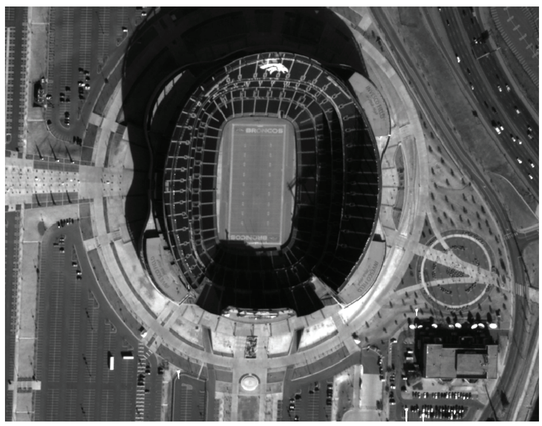

Figure 9. Localized urban area (QuickBird Panchromatic Image-Right)

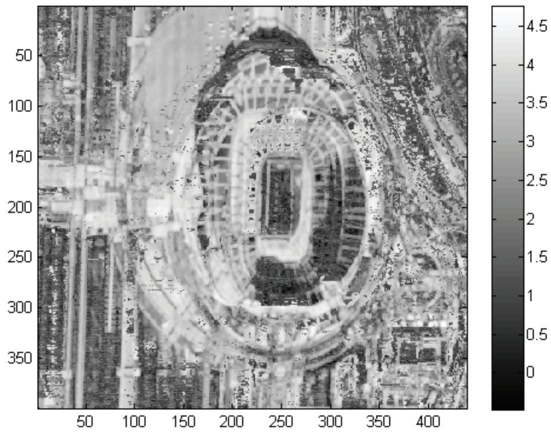

Figure 10. Disparity map for QuickBird Satellite Images (panchromatic)

We have also taken some remote areas with few building inside the jungle area as shown in Figure 11 and 12. Figure 13 shows the disparity map of remote area.

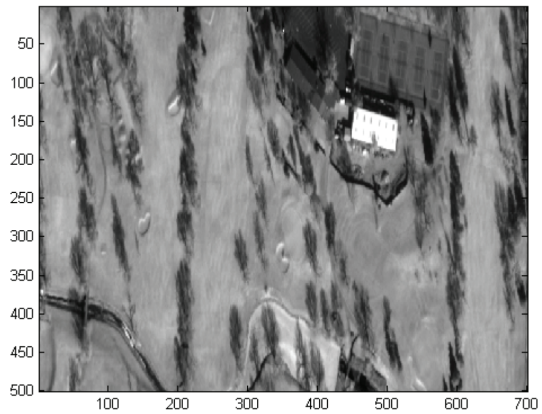

Figure 11. Remote area (QuickBird Panchromatic Image-Right)

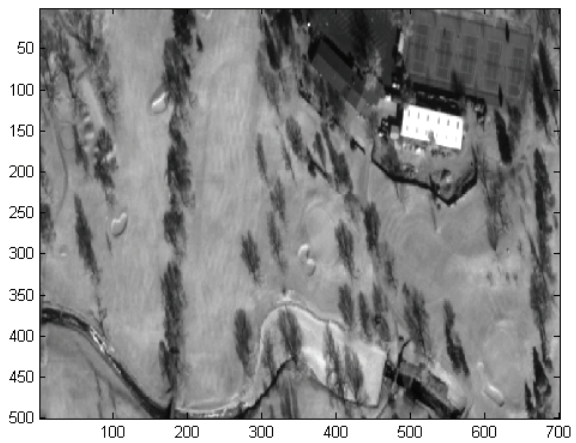

Figure 12. Remote area (QuickBird Panchromatic Image-Left)

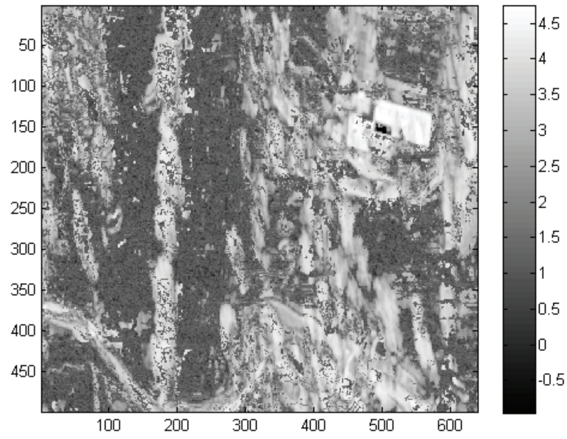

Figure 13. Disparity map for QuickBird Satellite Images (Panchromatic)

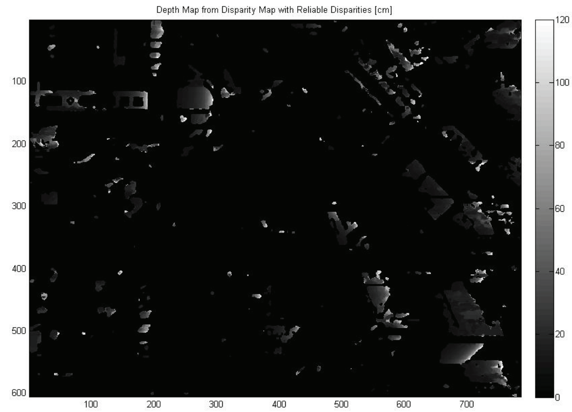

Figure 14. Depth map of urban area

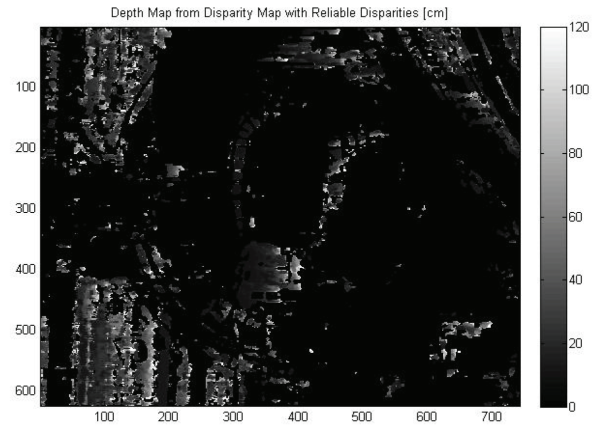

Figure 15. Depth map of urban area (specified structures)

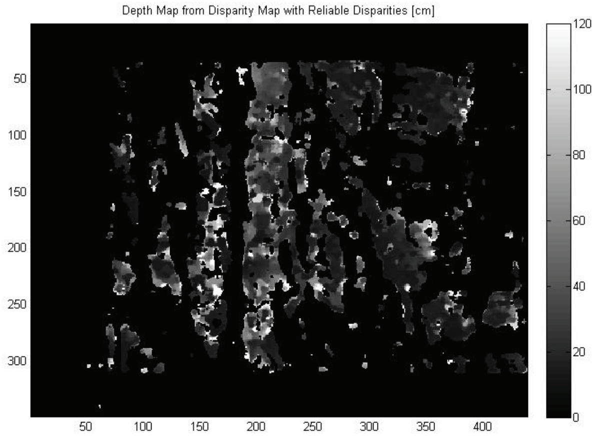

Figure 16. Depth map of remote area

Figure 14, 15 and 16 shows the depth maps of the urban areas, urban area with localized building structures and remote areas respectively. From these depth maps, we can mark the damage areas and can find the intensity of the damage by comparing these images with the previously acquired images from stereo satellites of the city stored in the data base before occurrence of the disaster. This can give us the quick view of the damage occurs in the specified areas.The major advantage of our proposed method in in term of cost. Satellite stereo imagery are inexpensive in terms of covering larger areas in short span of time. On the other hand, it is time consuming by doing video surveillance by helicopters or planes and also it is expensive.

V. Conclusion

For Disaster Management, satellite imagery play a vital role to start rescue activities in the most damaged and affected areas. Remote sensing techniques are used for this purpose and each technique has some pros and cons. Satellite imagery can be used to generate the maps which contain geospatial information extracted from satellite imagery of natural hazards

We have developed our method based on disparity maps and depth estimation algorithm to estimate the intensity of the damage occurred due the natural disaster. Three cases of urban area, localized structure area and remote area have been taken. It can support the government or decision makers during all the phases of disaster management cycle based on damage estimation by this method.

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