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"Development of Rainfall Measurement System using Digital Image Processing Based Multi- Sensor Approach"

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ABSTRACT

Rainfall is a natural phenomenon and its observations are frequently essential for flood warning and its monitoring. The conventional techniques which are used for rain measurement is rain gauge, radar and satellite, precipitation estimation with each technique has its own asset with restriction and the methods are supportive to some extent, providing information at different spatial and terrestrial scales. In this article, a new approach is developed to estimate rainfall from droplet images data using proposed signal processing algorithm. This proposed method uses multi-sensor image data captured by two orthogonal placed cameras. After selection of appropriate data image, it is enhanced for noise free and smooth edges then. Fusion of multi sensor image data gets more informative image followed by segmentation for rainfall parameter analysis. Finally, drop size distribution, rainfall rate and direction of precipitation with its intensity are computed using the proposed algorithm. The real time image data in the form of images / videos were collected at Indian Meterology Centre, Coloba Mumbai, during the day time from 24th July to 6th August 2016 and experiment results of the method are compared with rain gauge observation techniques at the same place. We found that mathematical computations are only involved in this method and most convenient alternative by portable (cellular) device over conventional tedious and laborious methods. It would be additional helpful to the disaster administrators the city, water dam administrators, traveler, piscatorial and farmers to know rainy condition in every side in advance.

Keywords: - Rainfall measurement, fusion, Drop size distribution, Tri-class thresholding, multi-sensor approach.

1. Introduction

Water is very foremost parameter on planet Earth which has abundant impact on all the nourishment. Rainfall varies every year and territory to territory. The tropical geographical ares such as like India, heterogeneity has been noticed in rainfall since many years it is known as special season in India, its impact elements like soil attrition, weather predict and other links like telecommunication networks.

Total amount of water in the liquid or solid form falling from clouds on the earth is termed as the precipitation. Precipitation may have any form of snow which is called as solid hastiness , it is in the nature of water, called as liquid hastiness.

Understanding of rainfall characteristic is of critical importance in meteorology. It includes variety of areas like signal processing and various types of distrometers measurement parameters. Rain information recorded is used in river, basin management, hydropower, and water supply and as community based flood warning scheme [18], [23], [14].

Rainfall measurement is significant because of the following reasons: (i) We can compare the amount of rainfall at various regions which assists to deduce amount of fluctuations in precipitation (ii) Rainfall recording for successive years can reveal periodical (usually yearly) fluctuations and can help us to plan accordingly based on the nature's patterns.

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1.1 Traditional rainfall measurement methods

Many traditional approaches have been developed to measure the rain falling in given area or in particular terrestrial area. These approaches are refered since decayed to collect rainfall information, there are some inaccurate information beinf collected through these techniques.

Rain gauges generally measure the precipitation in millimeters (sometimes as inches or centimeters). Rain gauge measurements can be of two types: (a) manually and (b) by automatic weather station (AWS). Rain gauge measurements have many constraints during measurements. It is not possible to record rainfall data in a hurricane and is irregular (eve n if the equipment survives) due to wind pressure. In addition to this, rain gauges only measures rainfall data in a localized area.

Following are the various types of rain gauges [12]:

- Weighing rain gauge
- Tipping bucket gauge
- Standard gauge
- Optical rain gauge
- Disdrometer

In addition to the above rain gauge measurement methods, satellite e precipitation estimates are also increasingly used in flash flood valuable information for analysis the radar or rain gauge coverage is poor or non-existent. Also, hustle Radars are used which provides precise information [15].

To examine and adjust the readings from weather radar and satellite-based systems, rain gauge measurements are employed. Additionally, it can be a primary source of observations. Recent advancement in precipitation measurement is the disdrometer which is used to obtain details on precipitation [16]. Rainfall size, velocity and orientation can be measured using the instrument called “disdrometer”. Disdrometer construction involves an illumination unit that produces the background illumination using a lamp, a mirror and a lens and two CCD line scan cameras. Rainfall presence in the measurement scan blocks the light and is detected as shadows by the digital CCD sensors.

1.2 Signal processing methods for rainfall measurement

Very few approaches are reported for rainfall measurement using signal processing (photographic method) in the literature. These photographic methods have been used to measure rain drop size and velocity especially in agriculture sprinkler applications.

Image enhancement techniques have been widely used in the image processing to improve image quality by enhancing weak signal and protecting strong signal. The proposed new technique having the references of image processing tools with discrete wavelet transform with a multi-scales frame structure to achieve achieve better results [7, 8]. In this proposed algorithm enhancements achieves subjective quality of images by protecting edges and finding similarities for continuity of drop boundaries because detailed of rain drops is important for information interpretation. Contrast is an important factor to distinguish drops as a objects from the background black curtain as a two adjacent surfaces. The geometric information achieved by using contourlet transforms. Image intensification alters the spatial impact, so that new image has its won interpreter in a vogue has significant improvement in its content.

b. Edge enhancement

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c. Contrast enhancement
d. Intensity and hue and saturation transformations
e. Density slicing

1.3 Motivation and contribution

Rain gauge measurements are easy and direct way for rainfall amount and rate computation; still it is subjected to various origins of errors. Few of the errors are.

– Wind-induced errors: During the rainfall measurement, rain gauges are raised above the ground level. The mass rain gauges are fitted more than the ground, the wind spin on every side of gauge decreases the amount of small rain drops collection. Wind corrections are advised monthly or daily in order to mitigate this error.

– Evaporation and Wetting Losses:- In case of long interval periodic data collections (in days), due to variation in temperature evaporation and wetting losses are observed more in collective-type non-recording type gauges. Amount of such losses are the function of several variables including temperature and humidity.

– Calibration and Instrument errors: Such kind of errors are present in tipping-bucket type rain gauges. Calibration and its adjustment with a tipping mechanism is required on regular basis to minimize such errors which is performed at a fixed small rain rate. Increasing rainfall rate increases such error sand some times over 3% rainfall of higher than 150 mm per hour.

Rainfall is collected from the funnel and ice or snow sometimes will not allow any subsequent water drop collection. Typical placement arrangement for rain gauge can be on buildings or trees (open area without any hurdles). In addition to above errors, the lack of a wind shield causes significant errors.

To estimate rain attenuation two parameters are enquired: (1) rainfall drop size and (2) rainfall rate. Water drop sizes are non uniform within the volumetric cells and are different at different time instances during rain fall, which correspond to different rainfall rates and hence changing rain attenuation.

To overcome these limitations of traditional precipitation measurement methods, a new image processing based automatic approach is developed for precipitation measurement. The proposed method uses multiple sensors image fusion techniques which work more effective to overcome the deficient single vision system by the optical data captured by optical sensors to present a final optical composite image data. The benefits of multi-sensor image fusion includes [21]:

1. Spatial and temporal coverage: different spatial resolution from various sensors may enhance the spatial coverage by fusing the information. The simpler is applicable to the secular dimension.

2. The reduced uncertainties: combined information from the multiple optical sensors could reduce the uncertainty as connected with the image sensing or corrective measurable decision process.

3. More reliability: The combination of number of sources may reduce noise and consequently enhances the accuracy for the parameter measurement.

4. Robust systems and performance: the data redundancy in the sufficient measurements could help the process robustness. In case of failure of one or more sensors, the developed system performs using the remaining sensors.

The proposed method consists of data collection unit (droplet images) having black colored background and two image sensing instrument placed orthogonally to sense droplets of same region by different angle. Droplet images data are used for processing to analysis the drop size distribution and rainfall rate. Images are pre-processed first (image selection using histogram and noise removal) and then image fusion technique is applied using Non Subsampled Contourlet Transform (NSCT). Experimental results using the Double-density and Dual-tree Discrete Wavelet Transform (DD-DTDWT) these are obtained and compared with NSCT results. Finally, rainfall measurement parameters are derived using image segmentation approach. The rain fall is computed and compared with rates observed by India Meteorological Department (IMD).

Major contributions of the proposed research can be summarized as follows:

1. First method using two camera based image processing to investigate the amount, intensity and type of precipitation (rain, snow and hail) with good accuracy.

2. Method provides statistical analysis of visual features (such as rain drop size distribution (DSD) and rainfall rate) upon rainfall.

3 Proposed method has following advantages over conventional methods: (a) Reduced wind induced errors (b) no evaporation and wetting loss (c) Accurate measurement of number of rain drops and (d) heavy rainfall measurement can be possible. The paper is organized as follows.

4. Proposed algorithm for rainfall measurement is described in section 2. First step, pre-processing of the captured image is explained in section 3. Non-subsampled Contourlet Transform (NSCT) and image fusion approach is outlined in the section 4.1. Last step, image segmentation is discussed in section 5. Section 6 depicts experimental results evaluated using image data captured by two image sensors. Section 7 concludes the article.

2. Related works

Wei, C.C [24] presented the Regional Extreme Precipitation and Construction Suspension Estimation System (REPCSES) for performing the rainfall forecast which refered to detect the service suspension length in construction projects. This REPCSES comprised two important functions such as regional the extremes precipitation and estimation model (i.e., Modules no 1 and no 2) and the construction suspension estimation model (Modules no 3 and no 4). Here, modules 1 and 2 was used to calculate the hourly rainfall occurred in the construction location and cumulative rainfall occurred in 24 h. Subsequently, the module 3 was used to obtain the hyetograph as well as the graphs from the module 3 was used to take decision about work suspension. Moreover, the rainfall was predicted by using the Deep Convolutional Neural Network (DCNN). But, this DCNN was affected by the overfitting issue, when the image size was high.

Han, J., Olivera, F. and Kim, D [9] developed the radar-gauge rainfall merging method for evaluating the areal rainfall. This work developed the two variations of the Conditional Merging (CM) method which integrated the ground gauge precipitation data of next-generation radar (NEXRAD). In first variant, the covariant equation was used to develop CM with Simple Optimal Estimation (SOE). Next, an extra Ground-Radar rainfall ratio was used in the CM-SOE to develop the CM-GR-SOE as second variant. The rainfall prediction using CM methods were high at high rainfall intensities. But, this CM-SOE and CM-GR-SOE was failed to provide the better performances in low rainfall intensities.

CALP, M.H [4] presented the hybrid model namely Adaptive Neuro Fuzzy Inference System - Genetic Algorithm (ANFIS-GA) to evaluate the regional rainfall amount. The parameters of the ANFIS was optimized by using the GA as well as GA was used due to its stuck parameters. Additionally, the GA delivered a closer relationship among the output and input model. The main objective of this ANFIS-GA model was to decrease the losses of life and ensured an appropriate management of water resources. Since this ANFIS-GA model was considered 243 rules for rainfall prediction. Hence, the complexity of the ANFIS-GA model were exponentially increased according to the increment in rules.

Wang, H., Zeng, Zhang, C., J., Ma, L. and Guan, L [25] developed the precipitation based evaluation model for rainfall measurement. This precipitation evaluation model was comprised four different steps. In 1st step, the wavelet coefficients for various scales and frequency channels were identified by using the Stationary Wavelet Transform (SWT). For Support

Vector Machine (SVM), the wavelet coefficients were given as input in the second step. In third step, the wavelet coefficients of rainfall are obtained by providing the wavelet coefficients of evaluated reflectivity. Subsequently, the inverse wavelet transforms were refered to get the rainfall measurements . Hence, the accuracy of the rainfall measurement was increased by combining the SVM and SWT. However, the abnormal cases and huge training data was caused the overfitting issue in SVM.

Jiang, S., Babovic, V., Zheng, Y. and Xiong, J [10] presented the rainfall measurement by using the recorded videos from the ordinary surveillance cameras. The rain streaks from real-world backgrounds were obtained by using the decomposition-based method. Next, the geometrical optics and photographic analyses were used to evaluate the rainfall intensity from rain streaks. Here, the decomposition-based method was effectively detected the rain streaks under complex backgrounds. However, this work failed to classify the rainfall intensity during the rainfall rate measurement.

3. Proposed algorithm for rainfall measurement

Fig. 1 shows flow of the proposed approach using NSCT based image fusion. Various steps involved in the rainfall measurement technique are outlined below.

1. Droplet image capture using sensor: Two image capturing sensors are utilized in the proposed approach to capture rain images. Both the sensors placed at an angle of 90dgree apart to cover maximum common area.

2. Pre-processing: Pre-processing steps consists of two major image processing operations. As the input droplet image captured by the sensor is of large dimension, it first resized into 512×512 image size for the computational simplicity. Secondly, the median non-linear filter is used to with the resized optical image so that impulse imurity without decreasing the image sharpness reduced .

3. Non- Subsampled Contourlet Transform: After pre-processing, the input image is decomposed using NSCT to improve invisible edges or weak features present in optical image data with sufficient strong edges. The geometric information due to multi-resolution, multi-scale NSCT can be used to distinguish weak edges from noises.

4. Image fusion: The NSCT helps to separate different frequencies component as the higher and lower frequency components of input source image in the same field and then the two seperate parts are fused together for clear and better understanding. The maximum energy algorithm is employed for fusion to combine coefficients which includes important features of the two source images.

5. Result analysis: By applying image processing techniques on the fused image various parameters including drop size, drop size distribution, rainfall rate and direction of rain will be computed.

4. Pre-processing`

In the pre-processing step, the image is first resized. The imaging sensor used to capture droplet images in this experimental setup produce image of size 2094×1944. All the images of size 2094×1944 are downscaled into the size 512×512 which requires less time for analysis. After down scaling the input image in to the desired dimensions, median filtering operation is performed to reduce the blurring of edges and significantly eliminates impulse noise without reducing the image sharpness.

5. Multi-resolution transforms and image fusion

5.1 Non-subsampled Contourlet Transform (NSCT)

NSCT based decomposition is employed in this study for image enhancement and image separation into high and low frequency bands. The main objectives of image modification by enhancements are to identify weak edges and hence weak features in an optical image with its original strong edges with features. The optical image analysis for denoising and edge protection is necessary with critical images to extract useful information, the present techniques to decompose images in a various fashion, and thus highly impossible as the geometric detailed data in the transformed domain for differentiating the weak edges from unwanted data. Henceforth, it either differentiating noises whenever it applied to noisy optical images. NSCT is briefly introduced in the following subsection .The NSCT is a totally shift-invariant and multiscale along with multidirectional transform which enables to design filter with better performance hence transform required to enhance the image in frequency domain. However, present approaches decompose input images in a separable form and in this process the back ground information with transform domain can be explored for identify weaker edges from the optical image data along with noises. Hence, it enhanced noise or adds stronger visible artifact, when it is subjected to impure images. NSCT is briefly introduced in the following subsection.

The NSCT with complete shift-invariant and its multi-scale along with and multi-direction transformation to make available to design selected fifilters with modified frequency selectivity to achieves efficient subband decomposition of filter bank. The NSCT at ita various application state proven as an effective tool for image de-noising and image enhancement [8]-[7]. The NSCT at its different application levels involves a bank of filters that seperate various in to two-dimensional frequency plane in different subb and as shown in figure2.Initially, a non sampled pyramid structured divides the input optical data signal into: (I) low pass sub band and (II) high pass sub band. Lateral stage non sub sampled differential filter bank seperate the high pass sub band into various direction sub-bands, the schemes are repetated with the low pass sub-band NSCT so that it exasperated in two shift invariant parts: (i) a non subsampled pyramid structure that confirm the multiscaled property (ii) a non subsampled differntial filter bank structure that provide directionalilty.

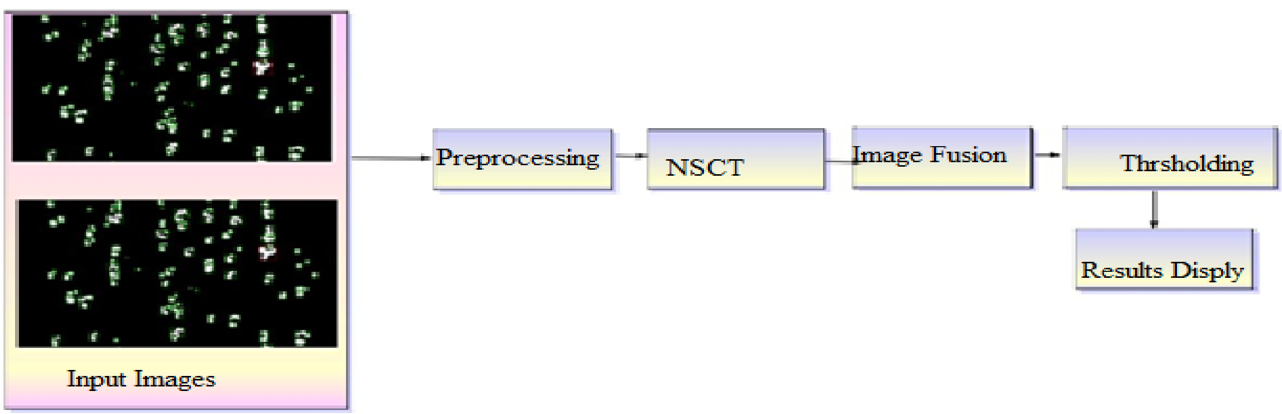

Figure 1 Image processing based rainfall measurement algorithm steps

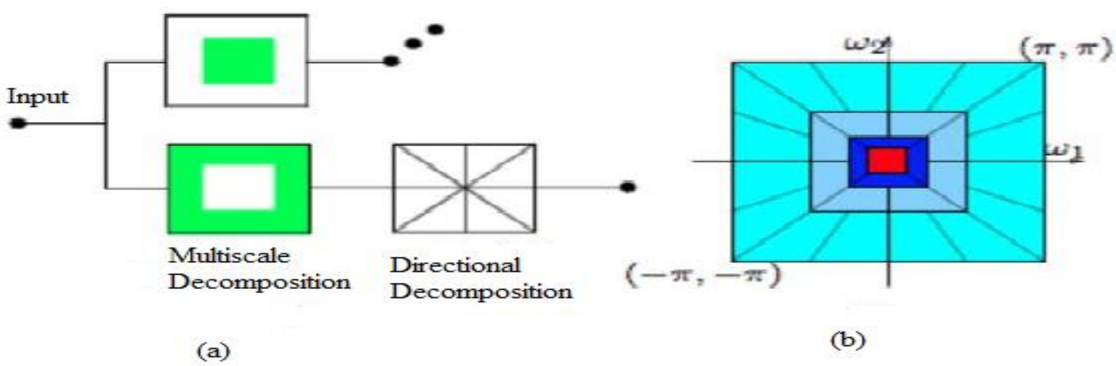

Fig. 2 The NSC transform: (a) Block diagram consists of a nonsub-sampled pyramid a nonsubsampled DFB (b) Resulting frequency division.

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Non subsampled Pyramid (NSP): Multi-scale characteristics of the non sampled conterllet transform achieved using a shift invariant filter architecture which attains a SBD so that the Laplacian Pyramid structure, it is obtained by with the help of two channelnon sub sampled 2-Dfilter banks. The filter for later stageis applied by up sampling the filters at the first stage, resulting in the multiscaled propertied without use of extra filter stage. Specifically, the NSFB of is developed from low-pass filter. The condition for the data reconstruction perfectly is described as

$$H_0(z)G_0(z) + H_1(z)G_1(z) = 1 \quad (1)$$

Non Sub Sampl Directional Filtered Bank (NSDFB): The directionality of the filter banks are constructed with the help of combination of critical sampled multiple channel fan filtered bank with the resampled operations. This operation generates as a tree-structur filter bank which divides the multiple dimensional frequency planes as per require

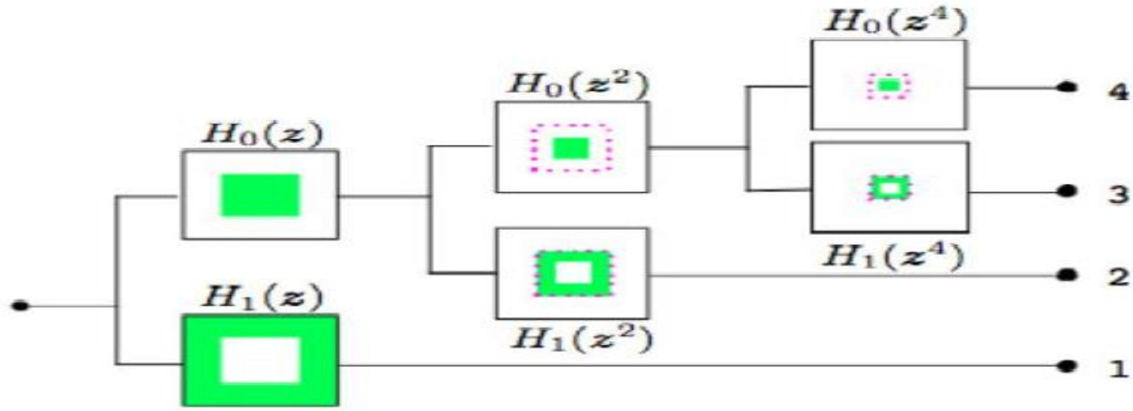

Figure 3, Iteration of mult channel non sub sampled filter bank based on non sub sampled pyramid.

Directional wedges [26]. A quincunx matrix employed for upsampling all filters is given as,

$$\begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix} \quad (2)$$

The shift invariant multi directional patterns are developed along with a non sub sampled DFB, the figure 4 shows analysis part of an iterated non subsampled multi directional filter banks. The NSDFB is structured with the help of eliminating the down samplers and up samplers in the differntial FB. To achieve the down samplers / up samplers in every 2-channel filter bank in the directional filter bank tree structure is employed with up sampling the filters accordingly. A new structure tree structure consists of multiple channel NSFB are generated using this process.

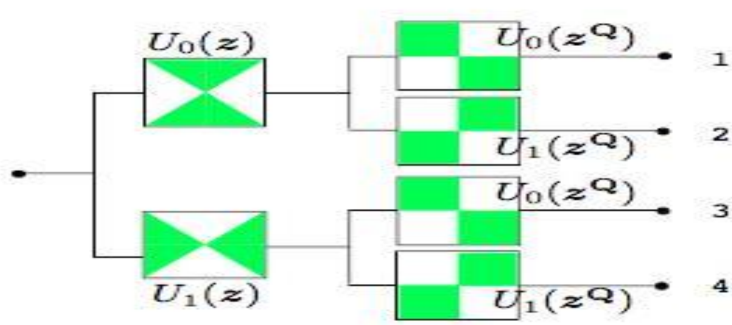

Figure . 4 Analysis Structrue of an iterated NSDFB

5.2 Double-density Dual-tree Discrete Wavelet Transform (DD-DTDWT

The modified structured dual-tree double density DWT based with concatenating multiple critically sampled DWT i.e. double-density discrete wavelet transform and the DT- DWT. The structure of the filter bank related to the dual tree DWT simply constructed of multiple critically sampled iterated parallel filter banks [2, 20,13].Undecimated DWT which is shift-invariant has inspire to the improvement with the double-density DWT. The scale function with multiple distinct wished wavelets were used in the DD-DWT. Double-density dual-tree DWT is developed by combining properties of the DD DWT and the DTDWT. It is based on the use of different distinct scale functions along with four different wavelets as

$$\psi h, i(t), \psi g, i(t), i = 1,2 \quad (3)$$

As per the equqtion number 3, the two wavelets $\psi h, i(t)$ are the offset of the another by one half, as is $\psi g, i(t)$, which given as

$$\psi h, 1(t) \approx \psi h, 2(t-0.5), \psi g, 1(t) \approx \psi g, 2(t-0.5) \quad (4)$$

An approximate Hilbert transform pair ψh,2(t) along with ψg, 2(t) is produced using two wavelets ψh,1(t) and ψg,1(t),

$$\psi g, 1 \approx H\{\psi h, 1(t)\}, \psi g, 2 \approx H\{\psi h, 2(t)\} \quad (5)$$

As stated earlier, DD-dual-tree DWT is based on the stricture of double-density DWT with the dual tree DWT as explained with [19, 20].

Key factors involved in the design are: (i) flatdelay filter (ii) spectral factorization and (iii) paraunitary filter-bank.

DD-dual-tree DWT is smoother than the dual tree DWT and it forms approximate Hilbert transform pairs. DT DWT filter structure involves two critically parallel sampled iterated filterbanks. Appropriate design of the two filterbanks results in higher performance in DT DWT. The filterbankconstructionpresentinDDDT-DWTinvolvesparalleltwooversampllediteratedfilterbanks, like DT-DWT. The oversampled filter bank is depicted in Fig. 5 [20].

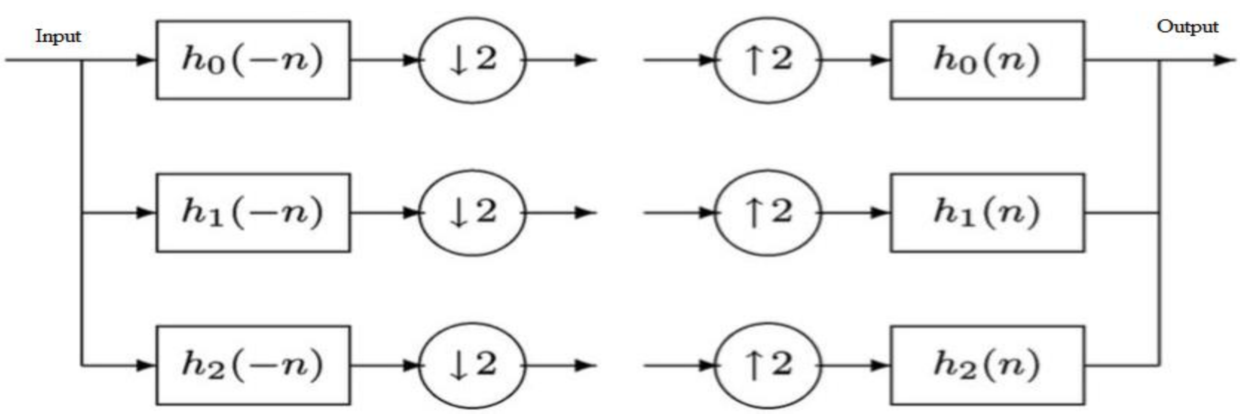

Figure. 5 Over sampled Analysis with Synthesis FB

The repetitively over sampled filter bank present with double density dual tree, is illustrated in Fig. 6 filters in the first filter banks are represented by hi (n) and the filters shown in the second filter bank given as gi (n), for i = 0,1,2. The filter banks considered in this study, the synthesis filter bank are the type of time reversed versions of the analysis filter bank.

The comparison of double-density DWT with dual-tree DWT are listed below:

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1) within the double-density DWT, the 2 wavelets are offset by way of one half while the dual-tree DWT the 2 wavelets form an approximate Hilbert remodel pair, 2) in the double-density DWT, the stages of freedom for layout is greater than the twin-tree DWT due to the fact fewer ranges of freedom for design (reaching the Hilbert pair property provides constraints), three) exceptional filterbank structures are used to enforce the twin-tree and double-density DWTs four) The dualtree DWT can be interpreted as a complicated-valued wavelet transform, that is useful for signal modeling and denoising while double-density DWT can not be interpreted as such. five) The twin-tree DWT can be used to put into effect 2-D transforms with directional Gabor-like wavelets, that's especially ideal for photograph processing whereas double-density DWT can be utilized in conjunction with specialized submit-filters to put in force a complex wavelet transform with low- transform with low-redundancy.

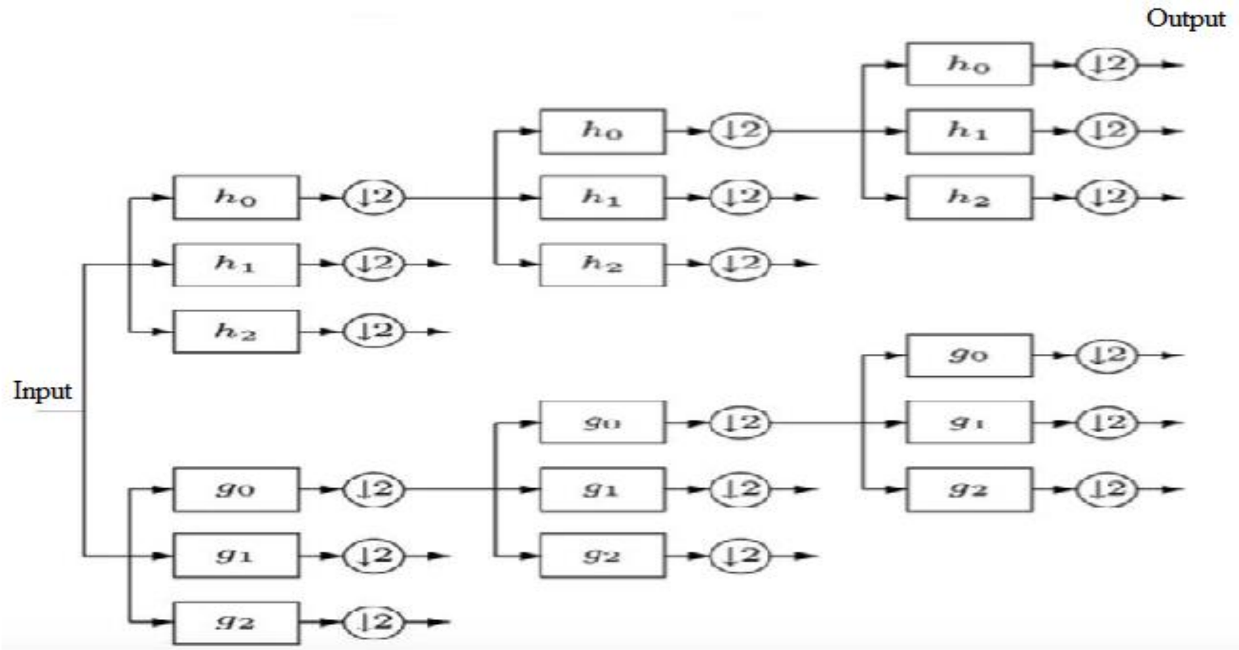

Figure. 6 Iterative Filter Bank for the DDDWT

5.3 Image Fusion Algorithm

For better interpretation of the image under observation various image fusion techniques are used. In the process of fusion the information is combined which is acquired by different sources. Image fusion is a popular choice in medical applications [5]. Specifically, the data fusion refers the new approach of combining multiple images of an same object resulting in a single image. The fusion of images allow revealing information and analysis in which several images of same object captured using different angles may produce new and improved image. The approximation characteristics of an image retried the low-frequency part and the high-frequency characteristics are projected using fine features of the edges. In this proposed, the NSCT decompression used to separate in to high and low components of input data image signal, later the 2 separate portion are fused for reliable and good understanding.

Maximum energy algorithm is employed for image fusion for the NSCT coefficients of the two source images. The fusion process is shown in Fig. 7. The proposed technique uses image fusion with the absolute maximumal energy selection fusion rules. Lets two different inputs are images A(x; y) and B(x; y) to be fused with heir efficient coefficients that are absolute maximum energy fusion is expressed as,

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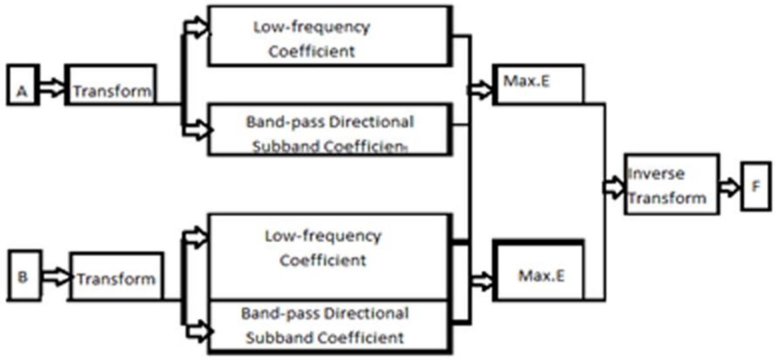

Fig. 7 Image fusion process using maximum energy algorithm

Fusion method performance and quality evaluation is an-alyzed using different parameters including: (1) Correlation coefficient (CC) (2) Standard deviation (SD) (3) Absolute mean square error (AMSE) (4) Percentage residual difference(PRD) (5) Peak Signal to Noise Ratio (PNSR) and (6) Quality index (Q). These measures represents amount of edge information "transferred" from source images to tar-get image. Larger the Q value, better is the performance of algorithm.

6 Image Segmentation using Iterative Triclass Thresholding

Objects of particular interest are extracted using the segmentation step. In this research, image segmentation using Otsus method is used. This method searches for sub-regions of the image for segmentation without using the entire image for processing [3]. Otsus method is utilized on an input during the first iteration. Output of first iteration is to extract the Otsus threshold and the means of two classes distinguished by the threshold. Later, the applied method classifies the im-age into three classes instead of two as in the regular Otsu's approach. Three different classes in triclass segmentation algorithm are defined. First magnificence includes the foreground with photo pixel values better than the larger mean. 2d class entails, the returned ground with photo pixel values lower than the smaller suggest. a third class is called as "to-be-determined" (TBD) class with photo pixel values ranging among the primary and 2d magnificence method. Then at the following iteration, the approach maintains the preceding foreground and history regions intact and again applies Otsu's method at the TBD region most effective to, again, separate it into three unique lessons in the identical manner. Stopping criteria for this process is based on the Otsu's thresholds calculation and comparing it with a preset threshold.

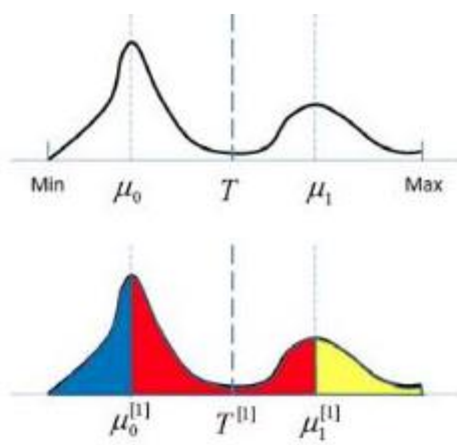

Figure. 8 Triclass iterative approach segments image into three classes (Bottom).

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Otsu's algorithm is exercised to obtain a threshold T[1] for the given input image μ in the first iteration. Means of the two classes back ground and fore ground separated by using the threshold are computed as μ[1] 0 and μ[1] 1 respectively. Next step to form groups of regions whose pixel represent higher than the μ[1] 1 as a foreground F[1] and the regions with pixel values lower than μ[1] 0 referred as background region B[1]. The other pixels belongs to u(x, y) lying in the range μ[1] 0 ≤ u(x,y) ≤ μ[1] 1 are represented 'to-be-announced' region class Ω[1]. We compute finally

$$U = F[1] \cup B[1] \cup \Omega[1] \quad (6)$$

Where as ∪ is union operation, the triclass algorithm performs better compared to original Otsu's two class approach.

7 Experimental results and discussions

Experimental setup for data collection of images includes a black colored background and two image sensing instrument placed orthogonally as shown in Figure 9. Arranged at Regional Meteorological Centre, Mumbai on 2 July to 7 July 2016 during day time for seven day, images sensing instruments with specification SONI DSC-H100 digital SLR camera, It also summaries the acceptability to receive triggering from external signals for proper synchronization which having exposure time 1/640 sec with focal length 32 mm. A micro-lens of size 200 mm with a spacer was used in the data collection system which have a higher magnifyfied image. The Field of view (FOV) of a image having resolution with 2592×1944 pixels was at 1.82×1.36 mm. The optical data configuration for current setup has provide focal length of 15 mm at distance 1 meter. The whole area covered a-b-c-d is one meter cube. Two separate images captured by DSLR are categorized as left focus images and right focus images with respective positions of cameras applied to processing unit for analysis.

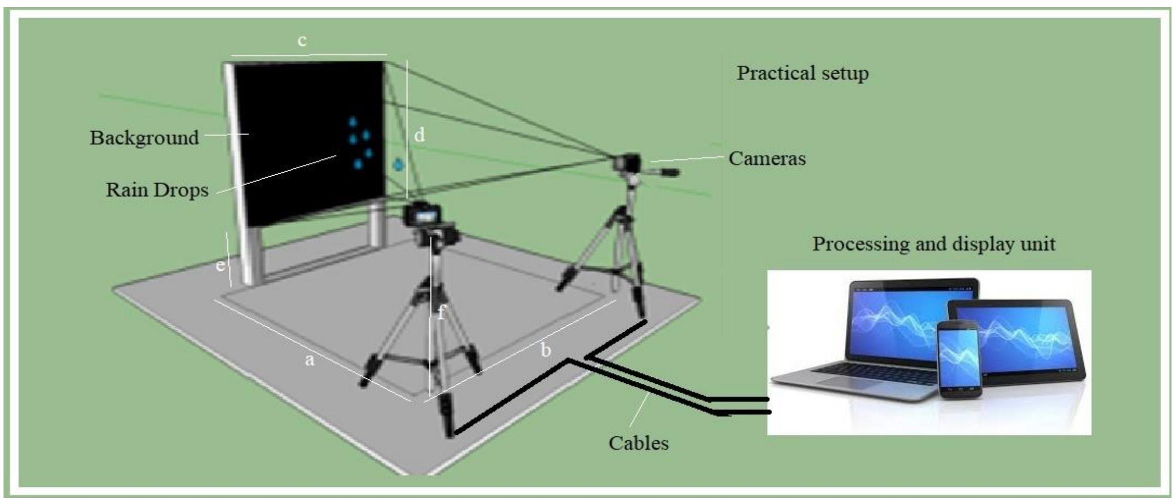

Figure. 9 Arrangement Experimental setup

7.1 Experimental results

Two digital images from left and right camera are captured from the procedure discussed above. Fig 10 and 11 shows left camera and right camera image captured by the experimental setup respectively. Spatial dimensions of this image are fixed at 512×512 size which is suitable for faster further processing. In order to minimize the effect of blurring and impulse noise, image sharpness intact, median filtering processing is applied over these images.

Next step in the algorithm is the fusion of left and right camera images. NSCT coefficients' of both images are fused together using maximum energy algorithm. Fig. 12 illustrates the fusion result. After obtaining single image using

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(a) (b)

Figure. 10 (a) Left camera image (b) Right camera image

The fusion, next stage is the segmentation step. Iterative tri-class segmentation approach is used as explained above, to obtain the segmented image. Various rainfall analysis experiments can be performed after the segmentation step.

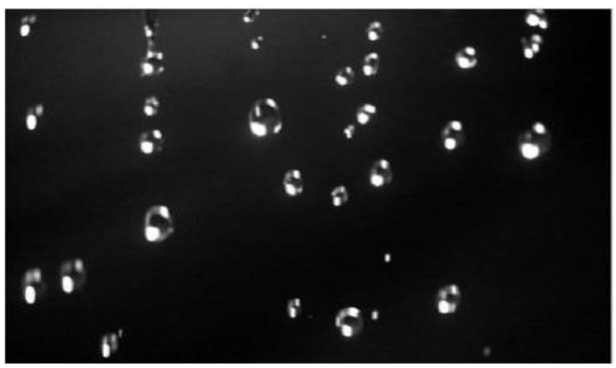

Figure. 11 Fused images

The segmented images used to identify the rainfall type and to count number of drops per frame for further analysis. Finally, by applying morphological operator erosion and labeling the drops are extracted using the connected components in the image.

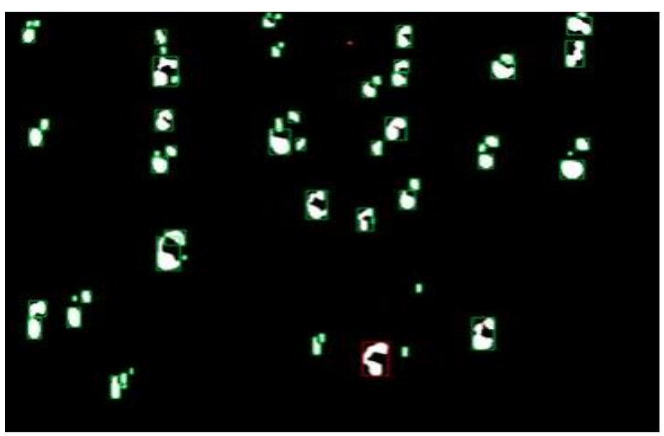

Figure. 12 Segmented Result of Fused Image

During the experiment we observed that, the histogram of DD-DTDWT fused image covers wider area than NSCT image. Hence, DD-DTDWT protects edges and give smooth drop size distribution which is useful in the analysis. The efficiency with quality of various measurement parameter of different data image fused and data are tested, the different parameters such as (i) Root Mean Square Error (RMSE) (ii) Peak Signal to Noise Ratio (PNSR) (iii) Correlation Coefficients (CC) and (iv) Quality Index (Q). The quality measures are related to information "transferred" from original images. The larger the Q value that means efficient is the algorithm performance. Table 1 shows fusion parameters using DD-DTDWT and NSCT based fusion for the proposed algorithm.

Table 1 Comparison of fusion parameters for DD-DTDWT and NSCT approach

Parameter → Method ↓	CC	SD	RMSC	PRD	PSNR	Q	Drop size(mm)		Avg Rainfall (15mm)
							small	Large	
NSCT	0.98	7.38	1.16	0.04	47.43	8.23	0.264	5.26	2686.4
DDDWT	1.00	3.70	0.95	0.01	49.56	12.73	0.646	5.99	2771.2
Experimental	-	-	-	-	-	-	-	-	2873.1

Rain drop analysis:Figure. 13 shows the drop size distribution in the frame captured by the source camera. The water drops may take either non spherical or spherical size. Both object sizes are considering in this study. The target are identified by using various image processing tools like morphological operations. The sphere object is identified by the mathematical formula and identified are treated as a non spherical. The outcomes may be vary from image to image and also vary from the actual drop following steps are involved.

Compute metric (volume) first using

$$\text{Metric} = \frac{4\pi \text{ Area}}{\text{Perimeter}^2} \tag{7}$$

Where, area = total volume area and perimeter = ∑ (p(∑(delta sq))). Threshold is set to compare to obtained volume.

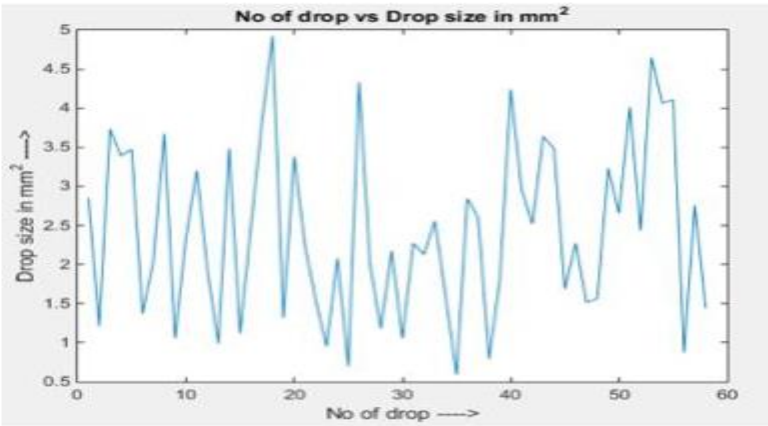

Figure. 13 Drop size distribution in frame

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If the value is greater than threshold value count, that drop as spherical otherwise it non spherical. Total count of drops and total volume is calculated as Total volume = volume of spherical +volume of non spherical, (2) total count=count of spherical + non spherical drops.Table 2 shows various parameters computed using both approaches. Total number of rain drops, smaller and bigger rain drops, volume of maximum rain drop and total volume of rain drop in an entire frame is computed. Figure 14 shows PSNR values obtained incase of NSCT and DD-DTDWT. As it is seen from the figure that, higher PNSR values are obtained using DD-DTDWT based experiments. Figure 1 depicts drop size distribution in mm and terminal velocity of the rainfall computed.

Table 2 Rain-drop analysis for DD-DTDWT and NSCT approach

Parameters	DD-DTDWT	NSCT
Total no. of rain drops	114	142
Smaller drop size in mm^2	0.264	0.373352
Bigger drop size in mm^2	6.741053	5.260163
Volume of Max Rain drop	4.599053	5.744107
(Ml) Volume of Rain drop in Entire frame	35.867173	28.400253

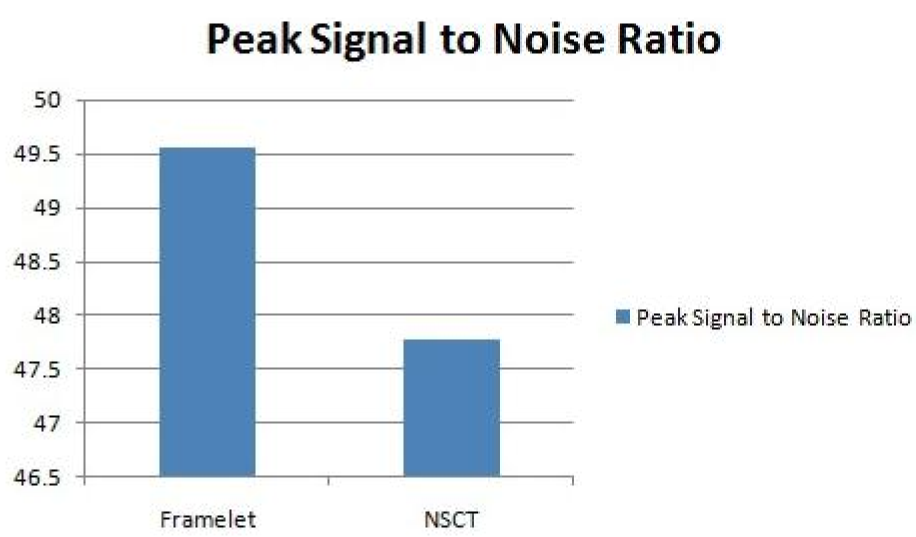

Figure. 14 PSNR values obtained

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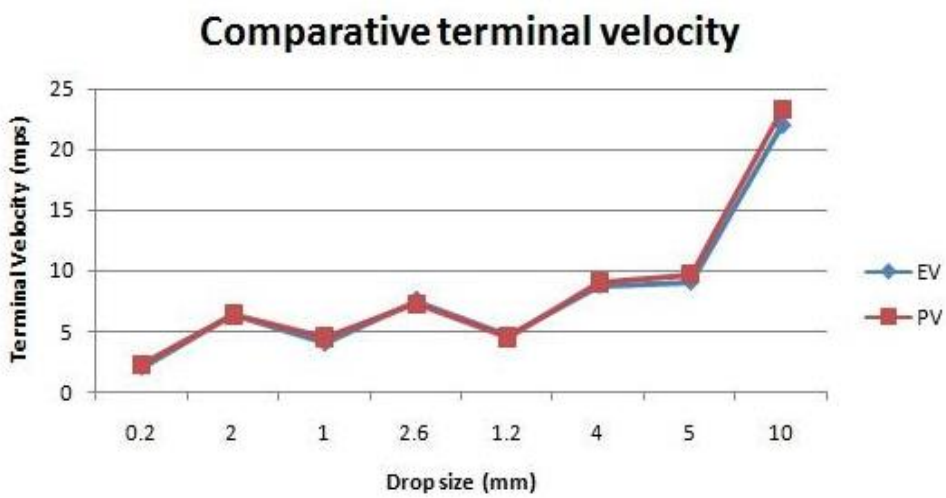
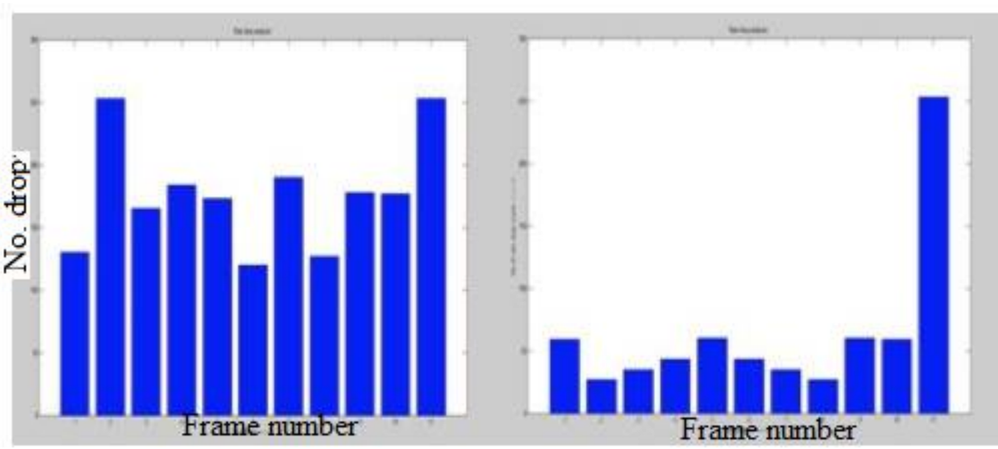


Figure.15 Comparative terminal velocity with drop size

Experimental results computed using the proposed system is compared with the rainfall data provided by the Regional Meteorological Center; Colob aMumbai.Table3 displays the comparison between experimental results and the rainfall of Regional Meteorological Center. Different parameters like drop size, terminal velocity and rainfall rate are recorded and compared. From the table that, when rainfall rate is low and moderate then percentage error found was very less. Experimental results are closely matching to the data obtained in this case. As the rainfall rate increases, error also increases.

Every frame of video snap of specific time has different average drop size which helps to define nature of rainfall rate whether it is steady or variable. Figure 16 presents one such the plot. It shows frame number versus average drops present in the frame.



(a)

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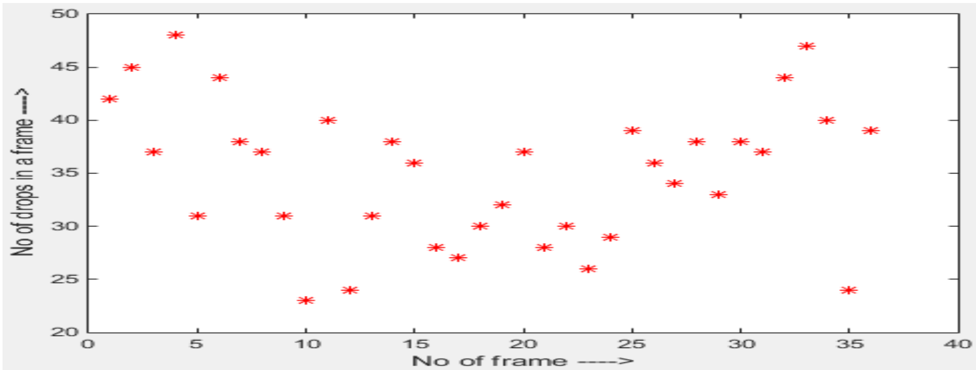

(b)

Figure..16 Frame number versus average drops (a) Line bar plot (b) Scattered plot

Table 3 Comparative Results

Rain Type	Drop size in mm	Terminal Velocity mps	**Terminal Velocity mps**	**Rainfall RPH mm**	Rainfall RPH mm	% Error
	Steven L. Horstmeyer (Relation)		**Experimental Results**		IMD	
Light Rain.04-1'' per hour				**.5775**	**.239**	1.702
Small Drop	.2	2.06	**2.25**			
Large Drop	2.0	6.49	**6.36**			
Moderate Rain (1-4") per hour				**33.4**	**36.74**	4.76
Small Drop	1.	4.03	**4.503**			
Large Drop	2.6	7.57	**7.261**			
Heavy Rain 4-16"				**106.1**	**154.6**	18.60
Small Drop	1.2	4.64	**4.51**			
Large Drop	4.0	8.83	**9.00**			
Largest Possible	5.0	9.09	**9.69**			
Very heavy rain (16-50 mm ph)	>10	>22.02	**>23.24**	**-**	-	-

8 Conclusions

A method using multi-sensor image data captured by two cameras is proposed for rainfall rate measurement. Segmentation based on iterative tri-class thresholding is used after fusing two sensor images. Drop size distribution, terminal velocity and rainfall rate are measured using the proposed algorithm. The method provides better alternatives to measure the rainfall measurement and analysis with numerous advantages.

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