Detection of Thunderstroms Using Data Mining and Image Processing

Kishore Kumar Reddy C, Anisha P R, Narasimha Prasad L V
Vardhaman College of Engineering
Hyderabad, India
kishoar23@gmail.com, anisha1990jan@gmail.com, lvnprasad@yahoo.com

ABSTACT: *Thunderstorm is a sudden electrical expulsion manifested by a blaze of lightening with a muffled sound. It is one of the most spectacular mesoscale weather phenomena in the atmosphere which occurs seasonally. On the other hand, prediction of thunderstorms is said to be the most complicated task in weather forecasting, due to its limited spatial and temporal extension either dynamically or physically. Every thunderstorm produce lightening, this kills more people every year than tornadoes. Heavy rain from thunderstorm leads to flash flooding, and causes extensive loss to property and other living organisms. Different scientific and technological researches are been carried on for the forecasting of this severe weather feature in advance to reduce damages. In this regard, many of the researchers proposed various methodologies like STP model, MOM model, CG model, LM model, QKP model, DBD model and so on for the detection, but neither of them could provide an accurate prediction. The present research adopted clustering and wavelet transform techniques in order to improve the prediction rate to a greater extent. This is the first research study carried on thunderstorm prediction using the clustering and wavelet techniques resulting with higher accuracy. The proposed model yields an average accuracy of 89.23% in the identification of thunderstorm.*

Keywords: Clustering, Haar Wavelet Transform, Image Processing, Remote Sensing, Satellite Imagery, Thunderstorm

Received: 2 September 2013, Revised 8 October 2013, Accepted 13 October 2013

1. Introduction

Thunderstorm is a vicious, climatic disturbance that is associated with heavy rains, lightening, thunders, thick clouds and gusty surface winds. Thunderstorms take place when a layer of warm and moist air rises to a larger extent, and updrafts to the cooler regions of the atmosphere. The updraft that contains moisture condenses in order to form massive cumulonimbus clouds and eventually leads to the formation of precipitation. Columns of frozen air then sink earthward, striking the ground with strong downdrafts and horizontal winds. Meanwhile, electrical charges mount up on cloud particles and causes lightning. This further heats the air in a fierce manner by which shock waves are produced, resulting in thunder [1].

Usually, thunderstorms have the spatial area for a few kilometers with a life span less than an hour. However, multi-cell thunderstorms have a life span of several hours and may travel over a few hundreds of kilometers [2]. A thunderstorm is said to be severe when it contains hail measuring of about an inch or more, winds gusting to an extent of 50 knots (57.5 mph). Throughout the world it is estimated that 16 million thunderstorms occur each year, and at any given moment, there are roughly 2,000 thunderstorms in progress. There are about 100,000 thunderstorms each year in the U.S. alone. About 10% of these reach severe levels. Under the right conditions, rainfall from thunderstorms causes flash flooding, killing more people each year than hurricanes, tornadoes or lightning [2].

Cloud to ground lightning frequently occurs as part of the thunderstorm phenomena, which on severity becomes hazardous to the property, wildlife and population across the globe to a major extent. One of the most significant lightning hazards is to the wildfires, as they can even ignite the ground surfaces. Wildfires can devastate vegetation and the biodiversity of an ecosystem. Recently, thunderstorms in Uttar Pradesh has taken more than 110 human lives and dented famous mango belt of U.P during May 15th 2008 [6]. In Canada, Alberta and southern Ontario are places best known for severe thunderstorms. In Canada the Saskatchewan Government Insurance estimated that 5900 claims cost close to $4 million and total damages were estimated at $10 million due to the thunderstorms. On 18th May 2013, United States incurred losses of about $125 millions to $250 million dollars due to the disastrous effect of thunderstorms.

Significant research work carried out in the last two decades for understanding the life cycle and the prediction of thunderstorm, still a challenging task to the forecasters and the researchers. The behaviour of thunderstorms is still subjected to the experience of the forecasters and the analysis of numerical weather prediction models. Thunderstorms were predicted based on the severity of the sounds of the thunder, statistical test and graphing were the other parameters used for the prediction purpose. This motivates the present research to utilize satellite images, which are high in quality and can be an efficient and effective source for the prediction purpose.

The thunderstorm identification methodology developed in this paper comprises of four stages. In the first stage, the satellite image is segmented in order to differentiate various textures like water body, forests, grass, asphalt, barren lands, concrete and clouds etc. The segmentation is based on k-means clustering technique 18] in order to extract the thunderstorm features from the original image. In the second stage, Haar wavelet transform [15-17] is adopted to acquire square root balance sparsity norm threshold value for the feature extracted image. In the third stage, the obtained threshold value is multiplied by wavelength factor to compute a wavelength range of the required image and this range should lie in between 380nm-750nm [14].

The outline of the paper is organized as follows: Section II gives a glance to all the recent researches. Section III gives a brief narration of how a thunderstorm forms. Section IV elucidates the proposed experimental methodology. Section V illustrates the experimental results and the graphically comparison of the present research with the previous ones and finally, Section VI concludes the paper.

2. Related work

Himadri Chakrabarty, Murthy C.A, Sonia Bhattacharya and Ashis Das Gupta [1] used Artificial Neural Network model in order to predict Squall thunderstorms by using RAWIND data. Litta A. J, Sumam Mary Idicula and Naveen Francis C [2] adopted multilayer perceptron network model to predict thunderstorms where in, the prediction was done using the data obtained from RSRW flight but this is limited to a particular region rather than the entire world prediction over Kolkata. Harvey Stern [3] used a knowledge based system to predict thunderstorms. Rudolf kaltenbock, Gerhard Diendorfer and Nikolai Dotzek [4] analyzed ECMWF, lightning data and severe storm reports for the evaluation of thunderstorms. Tajbakhsh S, Ghafarian P, and Sahraian F [5] adopted numerical weather prediction model in order to survey thunderstorms. Mahesh Anand S, Ansupa Dashi, Jagadeesh Kumar, Amit Kesarkar [6] adopted artificial neural network model for the prediction of thunderstorms. Alwin Haklander, Aarnout Van Delden [7] discussed how pressure, temperature, moisture and wind data from a single rawinsonde observation at DE Bilt can be used as an aid in estimating the probability of thunderstorm occurrence within 100km from De Bilt during the 6h following the sounding. Pinto [8] discussed annual values of thunderstorm days and annual temperature values in the city of Sao Paulo. Alan Czarnetzki C [9] discussed about nocturnal thunderstorms, which produces heavy rains. David Bright R, Matthew Wandishin S, Ryan Jewell E and Steven Weiss J [10] used a physically based parameter for lighning prediction. Ken Harding [11] discussed the formation of thunderstorms and its aviation hazards. Bill Nisley [12] discussed the formation and anatomy of thunderstorms.

3. Formation of thunderstorms

Thunderstorms may generally form and develop in any particular geographic location, perhaps most frequently within areas located at mid latitude when warm moist air collides with cooler air. Thunderstorms result from the rapid upward movement of warm, moist air, this can be represented in 3 stages named as the developing, maturity, and dissolving stage. The developing stage is when, the storm starts strengthening in this the warm, moist air rises above and gets mixed with the freeze air making the warm air to get colder resulting in condensation. In this stage, the cloud forms larger due to the instability in the atmosphere and moves to the next stage.

The maturity stage starts when the storm reach its peak and is well developed, including a strong, dense anvil along with updrafts and downdrafts and in this stage hail may also prevail When a storm does this, it means the storm is very strong and has capability to produce severe weather and tornadoes and in the last stage called the dissolving stage. The storm starts fading away, when the cool downdrafts begin to intensify, the storm begins to dissolve. These downdrafts basically push everything out of the storm. Depending on the type of storm, its life will last anywhere from 15 minutes to hours. Thunderstorms are said to be more likely when the dew point with in the atmosphere exceeds 10oC and it is said to be severe when the dew point starts reaching 13oC or more [4].

There are four types of thunderstorms: single-cell, multicell cluster, multicell lines, and super cells. Supercell thunderstorms are the strongest and the most associated with severe weather phenomena. Mesoscale convective systems formed by favorable vertical wind shear within the tropics and subtropics are responsible for the development of hurricanes. Dry thunderstorms, with no precipitation, can cause the outbreak of wildfires with the heat generated from the cloud-to-ground lightning that accompanies them. Other than within the Earth's atmosphere, thunderstorms have also been observed on Jupiter and Venus.

4. Experimental methodology

The supreme goal of this real time processing is to scrutinize the satellite images obtained from Indian Meteorological Department, in order to predict whether the cloud images produces thunderstorms or not. Initially, the original satellite image of clouds is taken as the input image for the experimentation. As the input image is a satellite image, it may restrain with different type of noises such as striping noise, speckle noise, blurs and so on which are ought to be removed. It may also contains various textures such as water bodies, forests, grass, asphalt, barren lands, concrete, clouds and so on. These textures are to be estranged to acquire the image of interest so that the other texture does not have an effect on the precise forecasting of thunderstorms. If the satellite image containing such types of noises and textures are analyzed, the result obtained may deviate from original value. So, the input image must be segmented.

Clustering is an efficient technique to segment the input image into several clusters based on similarity measure, here Euclidean distance is used as one of the similarity metric. In the present research, k-means clustering is adopted for segmenting the image [18]. Here, Segmentation is performed to image by based on various color factors because colors possess wavelength values. The image containing relatively similar wavelength values are grouped into different clusters. The image segmentation method is done in MATLAB R2011a.

The segmentation process applied for a thunderstorm satellite image is shown in figure 2(a) and the resulted clusters generated are shown in figure 2(b), 2(c), 2(d), 2(e) and 2(f) respectively. The feature extracted clustered image shown in figure 2(d), is analyzed further by applying wavelet transformations. Here, the Haar wavelet transform is adopted for the further analysis where decomposition is applied to the image in rows and columns by transforming from data space to wavelet space in frequency domain. As a satellite image is an RGB image, Haar wavelet transform automatically converts RGB image into gray scale image and further de noise the image and present it in one dimension. In Haar wavelet [15-17], soft thresholding is considered for computing square root balance-sparsity norm threshold value. From the Table 1, it can be observed that, whenever a thunderstorm is present in the feature extracted image in frequency domain, square root balance sparsity norm threshold value varies between 9 to 11. Soft threshold does not cause non- continuants at $c(k) = \pm\tau$. The overall methodology for the identification of thunderstorms in the present investigation is shown in figure 1.

The soft threshold expression is shown in equation (1).

$$\bar{c}_s(k) = \begin{cases} sign\ c(k)\,(c(k) - \tau),\ c(k) > \tau \\ 0, \qquad c(k) < \tau \end{cases} \tag{1}$$

For the determination of threshold values, equation (2) is used.

$$\tau = \sqrt{\frac{2\sigma^2 \log(n)}{n}} \tag{2}$$

Fixed threshold value is calculated by using equation (4).

$$\tau_k = \int_0^{255} \left(\frac{d\Delta}{d\lambda} \sqrt{\frac{2\sigma^2 \log n}{n}} \right) dn \tag{3}$$

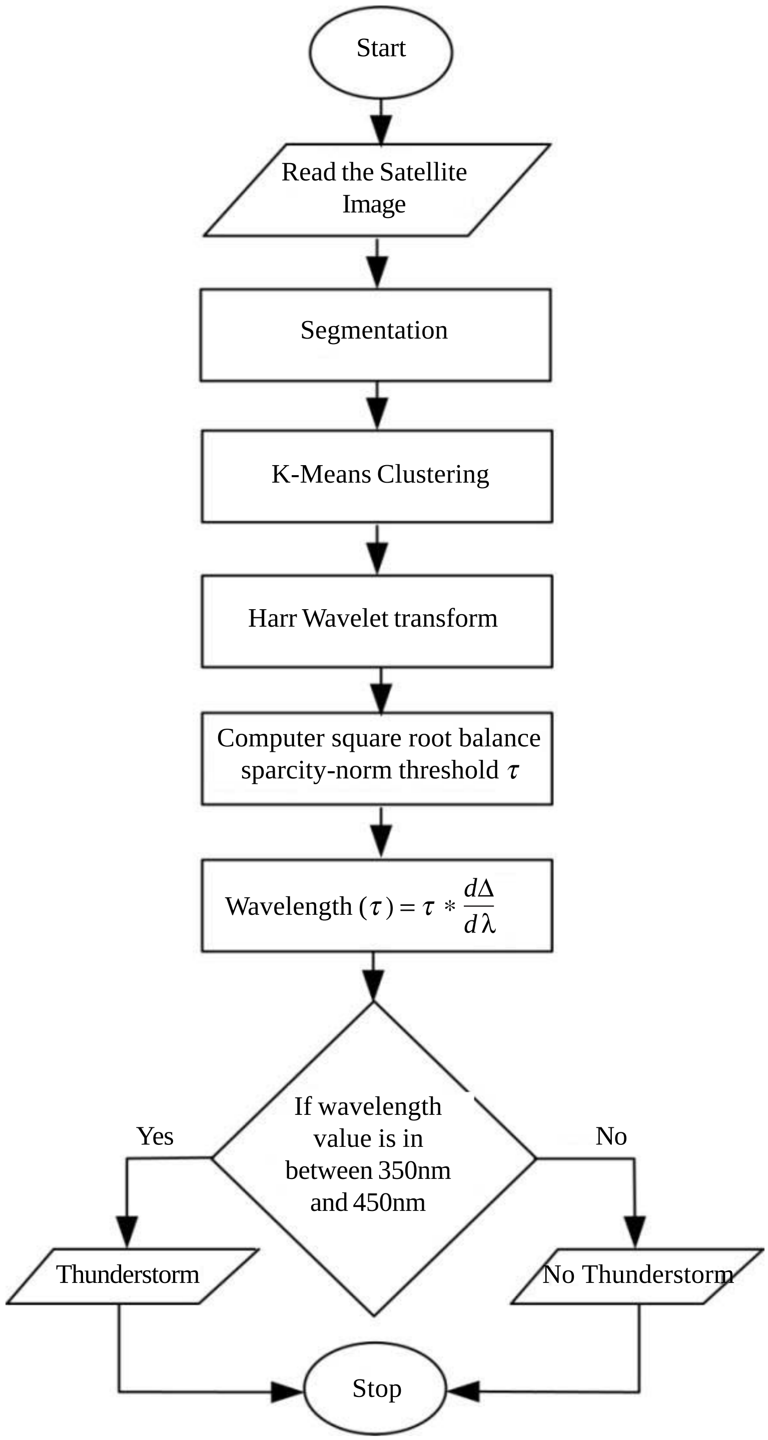

Figure 1. Procedure for detecting the thunderstorms

Now wavelength factor value is to be computed by using equation 3. Next, wavelength value is computed by multiplying wavelength value and square root balance sparsity norm threshold value. Now, wavelength ranges are computed by multiplying threshold value obtained and wavelength factor value. Here, a constant wavelength factor value is considered for the calculation of wavelength range. The constant wavelength factor value is the mean value. As the cloud satellite image is a visible infrared spectrum, its wavelength range would lie in between 380 nm - 750 nm [14]. From the Table 1, it can be observed that whenever a thunderstorm image is present, wavelength lies in between 380nm to 480nm which falls in the visible range. By experimentation, it is established that every thunderstorm image comprises a wavelength in between 380nm to 480nm, shown in Table 1.

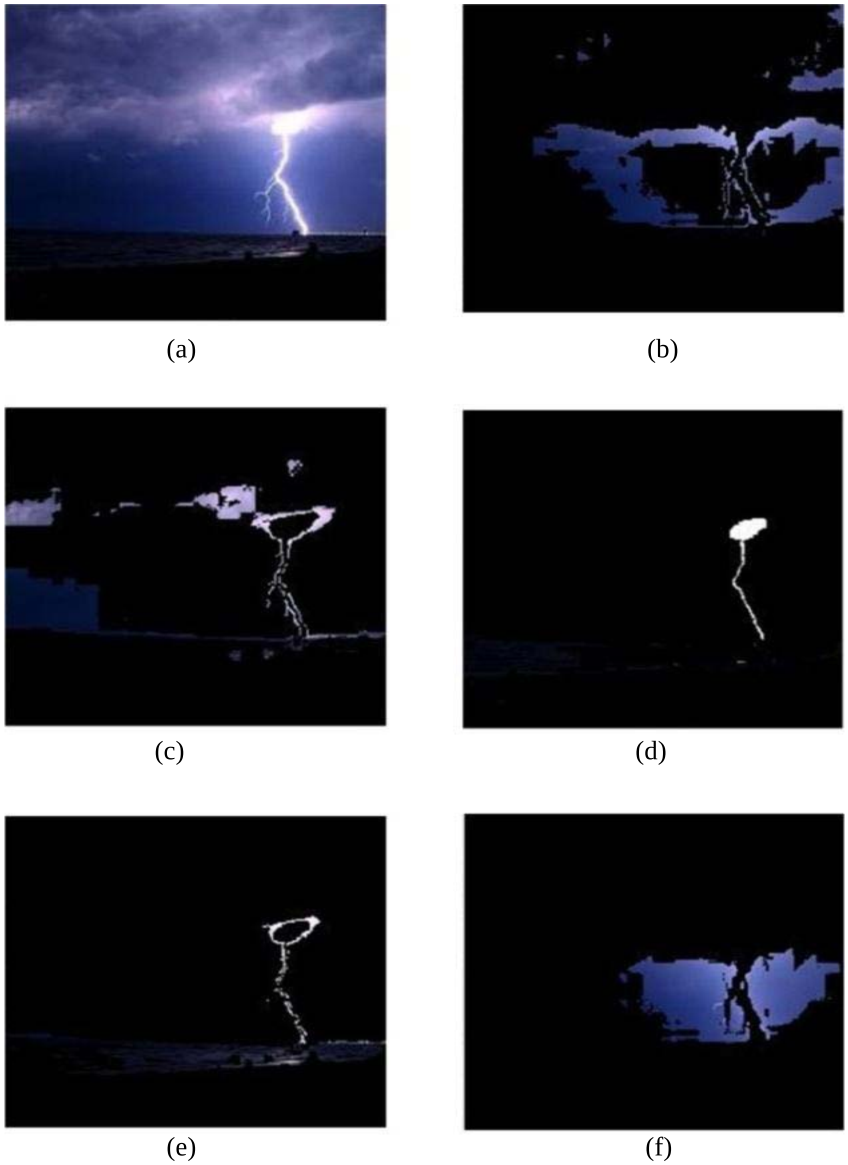

Figure 2. (a) Original image (b) Cluster 1 (c) Cluster 2 2(c) Cluster 3 (d) Cluster 4 (e) Cluster 5 (f) Cluster 6

The main goal of the present research is to detect the thunderstorms as accurate as possible. In order to compute accuracy for the present research *TP, TN, FP, FN* values are to be computed. The true positive (TP) specifies the positive tuples that were correctly labeled. The true negative (TN) specifies the negative tuples that were correctly labeled. The false positive (FP) specifies the negative tuples that are incorrectly labeled. The false negative (FN) specifies the positive tuples that are incorrectly labeled. The four basic performance measures i.e. sensitivity, specificity, accuracy and precision are computed for the present research in order to test how well the proposed system is working and the computations are done by using equations 4, 5, 6 and 7. Ideally, the proposed algorithm aims for 100% sensitivity 100% specificity, 100% accuracy and 100% precision.

$$Sensitivity = \frac{TP}{TP + FN} \tag{4}$$

$$Specificity = \frac{TN}{FP + TN} \tag{5}$$

Image number	Standard deviation (σ)	Square root balance sparsity norm threshold (τ)	Wavelength factor $\left(\frac{d\Delta}{d\lambda}\right)$	Wavelength $(\lambda) = \tau * \frac{d\Delta}{d\lambda}$	Historically established result
Image1.jpg	2.95	10.96	30.89	455.29	Thunderstorm
Image2.jpg	2.30	9.88	39.71	399.64	Thunderstorm
Image3.jpg	1.93	10.25	47.20	414.82	Thunderstorm
Image4.jpg	2.73	10.13	33.41	409.96	Thunderstorm
Image5.jpg	2.94	10.50	31.05	424.94	Thunderstorm
Image6.jpg	2.03	9.75	44.83	394.58	Thunderstorm
Image7.jpg	2.03	9.75	44.83	394.58	Thunderstorm
Image8.jpg	1.99	10.25	45.75	414.82	Thunderstorm
Image9.jpg	2.79	10.38	32.69	420.08	Thunderstorm
Image10.jpg	1.83	9.78	49.83	395.84	Thunderstorm
Image11.jpg	2.52	9.94	36.17	402.19	Thunderstorm
Image12.jpg	2.30	9.63	39.68	389.52	Thunderstorm
Image13.jpg	2.02	9.67	45.07	391.34	Thunderstorm
Image14.jpg	2.42	9.63	37.68	389.52	Thunderstorm
Image15.jpg	2.59	9.81	35.26	397.13	Thunderstorm

Table 1. Wavelength Rabge Establishement for Thunderstorms

$$Accuracy = \frac{TP + TN}{TP + FP + FN + TN} \tag{6}$$

$$Precision = \frac{TP}{TP + FP} \tag{7}$$

5. Experimental Results

In our study, the satellite images obtained from Indian Meteorological Department is analyzed to identify the presence of thunderstorms within the clouds. On analysis of these satellite images using MATLAB R2011a, a square root balance sparsity norm threshold value is computed and is established to be in between an optimal range of 9 - 11. As satellite image is a visible spectrum, its wavelength value always lies in the range of 380nm-750nm [14]. Based on this criterion, the wavelength range for the feature extracted images is tested and on observation of these results, a range of 380nm-480nm is established for the clouds containing thunderstorms.

The preliminary results presented in Table 2 shows that the wavelength of the thunderstorm image lies is in the range of 380nm-480nm. Consider an image16.jpg; its calculated wavelength is 531.37nm, which does not lie in the established range for the presence of thunderstorm. As the predicted experimental result represents no thunderstorm and the historical result represent thunderstorm, this indicates that the prediction is false. Also consider another image18.jpg; its calculated wavelength is 384.47nm, which lies in the range established for the presence of thunderstorm. As the predicted experimental result represent thunderstorm and the historical cloud image signifies thunderstorm, this indicates that the prediction is true. Consider an image 65.jpg; its calculated wavelength is 354.27nm, which does not lie in the established range for the presence of thunderstorm, even the historical data signifies no thunderstorm, this indicates that the prediction is true. Consider image 42.jpg its calculated wavelength is 464.23nm, which lies in the established range for the presence of thunderstorm. As of thunderstorm. As the predicted experimental result represents thunderstorm and the historical result represent no thunderstorm, this indicates that the prediction is false.

Image number	Standard deviation (σ)	Square root balance sparsity norm threshold (τ)	Wavelength factor $\left(\frac{d\Delta}{d\lambda}\right)$	Wavelength $(\lambda) = \tau * \frac{d\Delta}{d\lambda}$	Experimentally obtained result	Historically established result	Prediction
image16.jpg	3.76	13.13	24.25	531.37	No Thunderstorm	Thunderstorm	False
image17.jpg	1.38	8.00	66.28	323.76	No Thunderstorm	Thunderstorm	False
image18.jpg	2.59	9.50	35.24	384.47	Thunderstorm	Thunderstorm	True
image19.jpg	2.65	11.12	34.38	450.03	Thunderstorm	Thunderstorm	True
image20.jpg	1.94	10.37	47.08	419.67	Thunderstorm	Thunderstorm	True
image21.jpg	3.98	15.00	22.88	607.05	No Thunderstorm	Thunderstorm	False
image22.jpg	3.19	9.25	28.55	384.63	Thunderstorm	Thunderstorm	True
image23.jpg	2.21	9.50	41.24	384.47	Thunderstorm	Thunderstorm	True
image24.jpg	2.94	10.69	30.97	432.62	Thunderstorm	Thunderstorm	True
image25.jpg	2.34	9.13	38.93	389.45	Thunderstorm	Thunderstorm	True
image26.jpg	3.01	10.87	30.27	439.91	Thunderstorm	Thunderstorm	True
image27.jpg	2.53	10.50	36.05	424.94	Thunderstorm	Thunderstorm	True
image28.jpg	2.10	9.06	43.48	386.34	Thunderstorm	Thunderstorm	True
image29.jpg	1.65	9.38	55.17	381.24	Thunderstorm	Thunderstorm	True
image30.jpg	1.86	8.94	49.05	394.71	Thunderstorm	Thunderstorm	True
image31.jpg	2.39	9.63	38.18	389.52	No Thunderstorm	Thunderstorm	True
image32.jpg	2.50	10.31	36.43	417.25	Thunderstorm	Thunderstorm	True
image33.jpg	2.68	9.75	33.98	394.58	Thunderstorm	Thunderstorm	True
image34.jpg	1.94	9.63	47.05	389.52	Thunderstorm	Thunderstorm	True
image35.jpg	2.30	9.13	39.68	431.65	Thunderstorm	Thunderstorm	True
image36.jpg	3.27	11.00	27.90	445.17	Thunderstorm	Thunderstorm	True
image37.jpg	2.19	9.13	41.71	392.43	Thunderstorm	Thunderstorm	True
image38.jpg	2.12	9.60	43.01	388.63	Thunderstorm	Thunderstorm	True
image39.jpg	3.36	10.88	27.12	372.92	No Thunderstorm	No Thunderstorm	True
image40.jpg	2.90	15.13	31.43	543.62	No Thunderstorm	No Thunderstorm	True
image41.jpg	2.85	12.88	31.98	462.78	Thunderstorm	No Thunderstorm	False
image42.jpg	3.20	12.25	28.48	464.23	Thunderstorm	No Thunderstorm	False
image43.jpg	3.63	14.25	25.11	512.00	No Thunderstorm	No Thunderstorm	True
image44.jpg	2.12	8.75	42.99	314.39	No Thunderstorm	No Thunderstorm	True
image45.jpg	2.71	10.75	33.63	378.45	No Thunderstorm	No Thunderstorm	True
image46.jpg	2.59	9.88	35.19	354.81	No Thunderstorm	No Thunderstorm	True
image47.jpg	2.63	10.31	34.65	380.44	Thunderstorm	No Thunderstorm	False
image48.jpg	2.71	12.25	33.63	440.14	Thunderstorm	No Thunderstorm	False
image49.jpg	2.06	13.25	44.24	486.07	No Thunderstorm	No Thunderstorm	True
image50.jpg	2.17	9.60	42.00	344.93	No Thunderstorm	No Thunderstorm	True
image51.jpg	3.32	13.30	27.45	485.23	No Thunderstorm	No Thunderstorm	True
image52.jpg	1.84	9.80	49.53	352.11	No Thunderstorm	No Thunderstorm	True
image53.jpg	2.40	9.90	37.97	355.71	No Thunderstorm	No Thunderstorm	True
image54.jpg	1.90	10.38	47.97	372.95	No Thunderstorm	No Thunderstorm	True
image55.jpg	2.86	13.12	31.87	491.40	No Thunderstorm	No Thunderstorm	True
image56.jpg	2.32	9.06	39.28	325.53	No Thunderstorm	No Thunderstorm	True
image57.jpg	1.94	9.25	46.98	332.35	No Thunderstorm	No Thunderstorm	True
image58.jpg	2.67	9.80	34.13	352.11	No Thunderstorm	No Thunderstorm	True
image59.jpg	1.80	9.80	50.63	352.11	No Thunderstorm	No Thunderstorm	True
image60.jpg	2.56	9.25	35.60	332.35	No Thunderstorm	No Thunderstorm	True
image61.jpg	1.81	8.75	50.35	314.39	No Thunderstorm	No Thunderstorm	True
image62.jpg	2.22	9.18	41.05	329.84	No Thunderstorm	No Thunderstorm	True
image63.jpg	2.51	9.37	36.31	336.66	No Thunderstorm	No Thunderstorm	True
image64.jpg	2.40	9.75	37.97	350.32	No Thunderstorm	No Thunderstorm	True
image65.jpg	2.71	9.86	33.63	354.27	No Thunderstorm	No Thunderstorm	True

Table 2. Detection of Thunderstorms

From Table 2, the performance measures such as sensitivity, specificity, accuracy and precision are calculated using TP, TN, FP and FN and shown in Table 3.

The proposed method is compared with previous methodologies in the prediction of thunderstorms and is shown in Table 4. The comparison graph is drawn for all the algorithms and is shown in figure 2. The graph clearly shows that the proposed method is outperforming when compared with the previous methodologies.

Performance measure	Percentage (%)
Sensitivity	92.10
Specificity	85.18
Accuracy	89.23
Precision	89.74

Table 3. Performance Measures for Thunderstorms

Model	Accuracy (%)
STP model	39
MOM model	42
CG model	61
LM model	76
QKP model	38
DBD model	39
Proposed model	**89.2**

Table 4. Comparison of Proposed Model

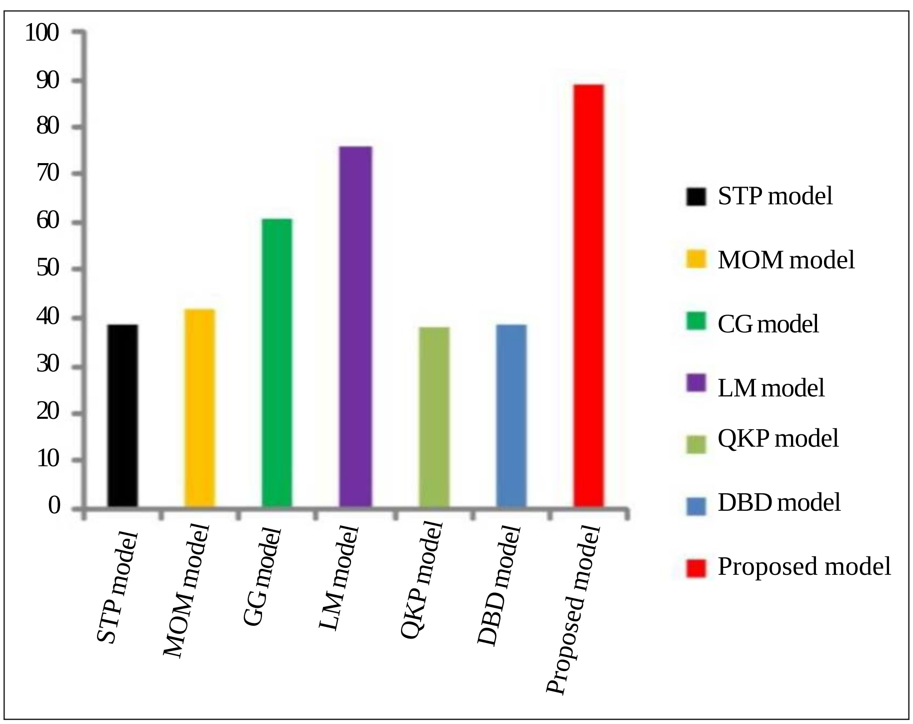

Figure 2. Comparison graph for proposed model

6. Conclusion

In this paper, experiments have been conducted with k-means clustering technique and Haar wavelet transforms for the prediction of thunderstorms. A statistical analysis based on square root balance – sparsity norm threshold and wavelength range has computed for the detection by using real time satellite imagery. This is the first study conducted to investigate the occurrence of thunderstorms by using wavelet transforms and clustering techniques. It was demonstrated that the resulting mechanism out performs the previous methods such as STP model, MOM model, CG model, LM model, QKP model, DBD model in the detection of thunderstorms. The proposed method predicts the thunderstorms with an average accuracy of 89.23%.

References

[1] Himadri Chakrabarty, Murthy, C. A., Sonia Bhattacharya, Ashis Das Gupta. (2013). Application of Artificial Neural Network to Predict Squall-Thunderstorms Using RAWIND Data, *International Journal of Scientific and Engineering Research*, p. 1313-1318.

[2] Litta, A. J., Sumam Mary Idicula, Naveen Francis C. (2012). Artificial Neural Network Model for the Prediction of Thunderstorms over Kolkata, *International Journal of Computer Applications*, p. 50-55.

[3] Harvey Stern. Using A Knowledge based System to predict Thunderstorms, Bureau of Meteorology, Australia.

[4] Rudolf kaltenbock, Gerhard Diendorfer, Nikolai Dotzek. (2009). Evaluation of Thunderstorm Indices from ECMWF Analyses, Lightning data and Severe Storm reports, *Atmospheric research Journal*, Elsevier, p. 381-396.

[5] Tajbakhsh, S., Ghafarian, P, and Sahraian, F. (2012). Instability Indices and Forecasting Thunderstorms: the case of 30 April 2009, Natural hazards and Earth System Sciences, p. 403-413.

[6] Mahesh Anand, S., Ansupa Dashi, Jagadeesh Kumar, Amit Kesarkar. (2011). Prediction and Classification of Thunderstorms using Artificial Neural Network, *International journal of Engineering, Science and Technology*, p. 4031-4035.

[7] Alwin Haklander, Aarnout Van Delden. (2003). Thunderstorm Predictors and their Forecast Skill for the Netherlands, *Atmospheric Research*, Elsevier, p. 273-299.

[8] Pinto. (2012). The Sensitivity of The Thunderstorm Activity in the city of Sao paulo to temperature Changes: predicting the Future Activity for Different Scenarios, International Lightning Detection Conference, p. 1-4.

[9] Alan czarnetzki, C. Evaluation of a Forecast strategy for Nocturnal Thunderstorms that Produce heavy rain, p. 25-31.

[10] David Bright, R., Matthew Wandishin, S., Ryan Jewell, E., Steven Weiss, j. (2005). A Physically Based Parameter for Lightning Prediction and its Calibration in Ensemble Forecasts," Confeerence on Meteorological Applications of Lightning Data, AMS, p. 1-11.

[11] Ken Harding. Thunderstorm Formation and Aviation Hazards. NOAA's National Weather Service, p. 1-4.

[12] Bill Nisley. Thunderstorm Anatomy and Dynamics. (1999). Naval Postgraduate School, california, p. 1-13.

[13] Anisha Ravinder, P., Prudhvi Kumar Reddy, K., Narasimha Prasad, L.V. (2013). Detection of Wavelengths for Hail Identification Using Satellite Imagery of Clouds, IEEE CICSYN, p. 205 – 211.

[14] http://en.wikipedia.org/wiki/Visible_spectrum

[15] Kanwaljot Singh Sidhu, Baljeet Singh Khaira, Ishpreet Singh Virk. (2012). Medical Image Denoising In The Wavelet Domain Using Haar and DB3 Filtering, *International Refereed Journal of Engineering and Science*, p. 1-8.

[16] Yang Qiang. (2011). Image denoising based on Haar wavelet transform, IEEE Internatonal conference on Electronics and Optoelectronics, p. 129-132.

[17] Candra Dewi, Mega Satya Ciptaningrun, Nmuh Arif Rahman. (2012). Denoising Cloud Interference on Landsat Satellite Image Using Discrete Haar Wavelet Transformation, *International Journal of Computer Science and Information Security*, p. 27-31.

[18] Fraley, C., Raftery, A. (1998). How Many Clusters? Which Clustering method? Answers via Model-Based Cluster Analysis," *The Computer Journal*, p. 578-588.