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Spatial Information System Architecture for the Geographic Information System

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Abstract*: Geographic Information System (GIS) combines software, hardware and data for the catching, handling, analyzing and displaying the different types of geographic information. This information can be in the form of digital maps, images taken by the satellite, aerial pictures, data captured through Global Positioning System (GPS), etc. Satellite imagery or Aircrafts specifically unmanned aircraft systems are used to capture images or geographical information. GIS has been greatly in use in various fields such as in Street Network, Land Information System, Facilities Management, Environment and Natural Resources Management, Planning and Engineering field, etc. GIS is the foundation of the various types of location enabled services. GIS system provides accurate maps or the pictures data captured with the help of various tools and techniques for the analysis of particular situation. In this paper, we are going to study the different aspects of the geographic information system such as land management, roof top analysis, traffic analysis, demographic analysis, watershed analysis, etc. Later we have compared LiDAR, satellite input processed with different feature extracted techniques with our proposed hybrid CNN approach. The result achieved is promising as compared with others

Keywords: Geographic Information System, GPS, unmanned aircraft system, satellite image.

I. INTRODUCTION

This Geographic Information System (GIS) is the key term related to the geography which can handle all types of geographical as well as geospatial data. So, we can collaborate data with the geography to understand what belongs to where. GIS data can be viewed in the form of maps and 3D scenes which focuses on the patterns, situations and relationships. It is a combination of spatial data and attributes data. GIS is one of the effective problems solving and decision making tools through spatial data analysis. GIS is used to identify the things, densities, quantities, nearby things, locations, etc. 80% of the data is geographic GIS stores information about the real world as thematic layers. GIS data is stored in the form of raster (grid) and vector image format. GIS is highly utilized best by the environmentalists to identify the change in climate and to identify underground source of water. It has also proved itself beneficial in the fields like agriculture, forestry, real estate, land management, supply chain management, media, military and defense, investigation field, public safety, transportation, education, etc. [1][2][3][4][48][49][50]

The application of GIS in recent study has shown higher potential for better societal benefit. A few of the applications are:

i. **Marine Time Safety and Traffic Control:** GIS can be useful in evaluating transportation RISK analysis and traffic safety. [1][8][9][39]52]

ii. **Earthquake Disaster Management:** The cost of delay in providing the help to the earthquake victim are very high. GIS can help in providing the information related to affected area which can be further classified and can help the disaster management team for quick action. [2][19][23][27]

iii. **Agricultural land-uses:** Statistics related to agriculture information are infinite and GIS can prove of great help to classify and distinguish the agriculture land from non-agriculture land. [3][13]

iv. **Road or Building Footprint:** GIS enables to get the accurate terrain, road maps, waterways and the footprints and heights of buildings. [4][5][18][20]

Apart from the above application areas, GIS has also been used to provide statistics for flood or cyclone affected area, potholes detection, tracking vehicle and geographical changes. [10][17] [47]

In this paper, we are going to study the different aspects of the geographic information system such as land management, roof top analysis, traffic analysis, demographic analysis, watershed analysis, etc. This study would provide an understanding of various techniques and methodologies such as feature extraction, data extraction used by GIS with different scenarios. The paper is put down in the following manner. Firstly, the GIS data sources and prior roof geometry classification work has been put ahead. Secondly, background in machine learning and data extraction methods is explained. Furthermore, a detailed performance analysis of algorithm is discussed on various dataset which is followed by the conclusion.

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II. LITERATURE REVIEW

GIS consists of three terms namely, Geographic, Information and System. Geography indicates that locations of the data items are identified in terms of geographic coordinates like latitude, longitude, magnitude, etc.
Information indicates that data available in GIS is organized in such a way that we can produce useful knowledge in terms of colored images and maps, statistical graphs, tables, etc. System refers to various inter linked components having different functionalities that make GIS. GIS performs a number of functions like data capture, modeling and output, input, manipulation, transformation, visualization, query, analysis, etc. GIS is used to manage information about places and to link databases and maps. It offers information and handling strategy for problem solving and to improve decision making. [6][7][34][40][42]

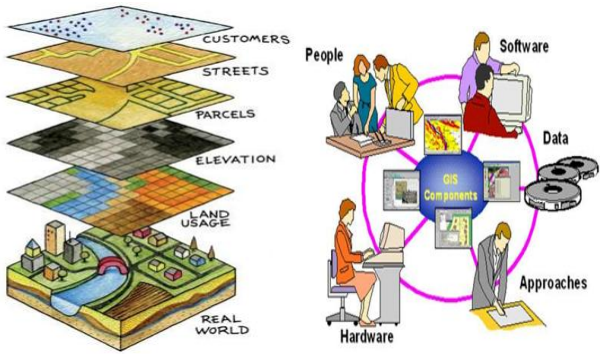

Fig.1 GIS Layers and Components [28][29]

A. Objectives of GIS: [4][11][54][53][51]

- Identify principles and functional problems pertaining to physical geography applications of GIS.
- Study, examine and review specific application areas or regions where GIS is a useful tool
- Explore methods provided by GIS which have specific significance to physical geography applications and problem solving.
- Classify and address problem areas such as data sources, modeling, error and uncertainty.

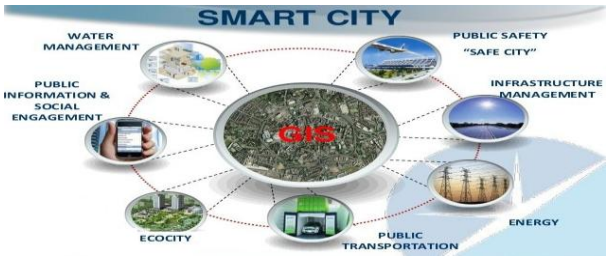

Fig.2 Smart City using GIS Application [30]

B. Features of GIS:[38][43][44][45][46]

- Multidimensional- At least two coordinates should be identified to describe a location.
- Voluminous – A database of geographic nature can easily extend to terabyte in size.
- Different Representations – The representation of the data can intensely influence the ease of analysis and the outcome.
- Requires unique analysis methods.
- Analyses require data integration.
- Map displays require fast data retrieval.

GIS also benefits in both geographical and thematic components of data. By stressing on the geographical aspects of a research question, it allows handling and exploration of large volumes of data as well as allows integration of data from widely disparate sources for the analysis of data to explicitly incorporate location. It allows a wide variety of forms of visualization. So, essentially, GIS is a connection of data with the geography to understand "what belongs to where". GIS creates geographic data, manages it, analyzes it and finally, displays information on the map. [4][35][36][48][50][[41]

C. GIS-Based Simulation Methodology for Evaluating Ship Encounters Probability to Improve Maritime Traffic Safety

Ming Zhao , Xufei Yao, Jun Sun, Shuning Zhang, Jing Bai proposed a scheme for the evaluation of the ship encounters probability which was based on the agent based simulation paradigm to improve the sea traffic safety with the help of intelligent algorithms which could be based on the Geographic information system. On the basis of the proposed methodology, a prototype was applied in the mid-western waters of Bohai Sea of China to test the accuracy. The proposed scheme is capable to direct for the future sea transportation. [1] [4] [15]

Agent based simulation discussed in the above paper is a simulation method also known as multi agent system and is capable of modeling discrete actions and communication of the agents in multifaceted adaptive method. ABS is used to model various traffic and transportation systems. ABS modeling approach supports a group of agents and interaction rules in specific atmosphere. ABS has the ability to avoid the crashes in different kind of situations and enables to identify the uncertainties and allows interaction with agents. These are the key parameters of ABS which is lacking in other complex simulation models. ABS is logically applied in the maritime traffic system. It is impressively powerful in the environmental perceptions and smart communication with the agents. A probable block or drawback of assessing the possibility of the ship encounter is to project position between vessels and to recognize the encounter situations with different traffic flow. [1][12] [16] [21][26][33] Intelligent algorithm discussed in the above paper is for assessing and identifying latent ship encounter conditions in order to increase the capability, flexibility and intellect of the simulation model. The Intelligent Algorithm is based on the geospatial analysis theory of GIS. [1][4] Initially, data capturing and analysis is done with the help of GIS and then, the generated useful information is provided to the traffic simulation model.

This model generates information like ship size, type, routes on the basis of vessel generation, vessel route and vessel navigation model. Furthermore, this information provides an intelligence algorithm for discovering probable situations which can be responsible for ships' encounter and for calculating traffic density in the specific region. Finally, experiments are conducted by the simulation to identify the traffic conditions in specific region and for calculating future maritime for the better traffic management. The simulation is carried out using two phases. Phase I deals with the traffic simulation models where assumption are Model Assumptions, Vessel Generation Model and Route Model. The Way points are evaluated using Geographic coordinates (Xi, Yi), as eq(1)

$$\mathbf{Wi\ (Xi, Yi)\ i = 0, 1, 2, \bullet\ \bullet\ \bullet, n,} \qquad \mathbf{(1)}$$

Where n is the total number of waypoints and W is way points.

Phase II that is Vessel Encounter Detect Intelligent Algorithm deals with the Vessel Domain Model that provides security issues such as collision avoidance between the ships. The indicators or parameters that act as input are distances, shape, size, speed, maritime conditions, etc. Finally, the models evaluate statistical input data and provide the ship encounter situations. The output data is used for the future planning, routing, etc. of the maritime traffic flow. It can consider the speed, overtaking time, crossing time, lanes of normal navigation, specific routes for precautionary areas, various regions, traffic density, ship encounter rate, etc.[4]

R= ratio of no of encounter situations in particular zone in a specific time slot to no. of ships exposed to encounter risk.

$$\mathbf{R = \sum N/\sum S \ldots\ldots\ldots\ [4]}$$

where,

R= Encounter Rate

N= no. of encounter situations in particular zone in a specific time slot

S= no. of ships exposed to encounter risk

The suggested findings highlight the potential "exposure" of ships to collision hazard and the increase of regional traffic volume that puts forth s new perspective for making decision for marine transportation planning community.

D. GIS-Based Rapid Disaster Loss Assessment for Earthquakes

S. Zhang, K. Yang, Y. Cao studied the various aspects of the earthquake disaster assessment to analyze the GIS based quick examination of the field for helping the government for faster rescue operations. The correctness and the competence of the spatial distribution of disaster fatalities can be enhanced through the various estimation model integrated with the GIS. Assessments can be done rapidly with the seismic location and magnitude. To compare 4 earthquakes data collected to show the accuracy on the basis of the thematic map, the mean accuracies are found to be 97.5% and 76.5% for the affected area. The architecture is based on the Isoseismal Attenuation Model. Seismology and seismology isoseismal maps are used to evaluate intensity for a specific earthquake. This is basically used to identify the loss assessment and hazard. [2][11][19]

During an earthquake, the point when two surfaces or blocks of earth slip unexpectedly from one place to another under the earth surface from where the earthquake start is known as hypocenter and the surface on the earth is known as epicenter. Due to the earthquake disaster, various regions get affected and there is always a need to calculate intensity of losses considering the damaged building assessment, economic loss assessment, fatalities assessment. [23][27]

Assessments can be done speedily with the seismic location and magnitude. Comparing the 4 earthquakes namely, Yongshan 5.3 earthquake, Yingjiang 6.1 earthquake, Ludian 6.5 earthquake and Jinggu6.6 earthquake, the data collected signifies the accuracy on the basis of the thematic map to the mean accuracies as 97.5% and 76.5% for the affected area. Mean accuracies for the fatalities and economic losses is more than 50% i.e. 66.1% and 54.25%, respectively. The number of affected population, damaged houses and injured persons are calculated with the mean accuracies of 45.24%, 38.5% and 17%, correspondingly.

E. Boundary Delineation of Agricultural Fields in Multitemporal Satellite Imagery

H. C. North, D. Pairman and S. E. Belliss proposed a method based on the segmentation for identifying the boundaries around the field in agriculture landscape surrounded by the polygon with the help of time series satellite imagery. The main focus or the criteria is edge linearity for the long distance as compared to the spectral difference. The proposed method is more accurate in classification of the filed than the individual pixel. [3] The method is used to increase the possibilities to identify and visualize the boundaries from the given images for this SPOT satellite used for image generation. The data from the date 18-2-10 to 21-08-11 collected through SPOT 4 and SPOT 5 satellite around the 4000 km2 area is considered for the experiment. Locational accuracy metrics for average distance from pixels in segment pixels to nearest pixel in reference boundaries is 5.05m in field boundary and 5.78m in imagine segmentation. Percentage of pixels <=10 from the reference boundary is 90% in field boundary and 88% in imagine segmentation. The method is robust with the consideration of the satellite imagery with medium resolution for the field scale mapping. [3][13] The proposed method is more accurate than the spectral difference for separating fields and segregate data like crops, roads, fields, etc.

F. Roof Shape Classification from LiDAR and Satellite Image Data Fusion Using Supervised Learning

Jeremy Castagno, Ella Atkins proposed a scheme to identify the roof top structure of the buildings by considering the existing GIS data available publically with the help of data fusion of Satellite Imagery, Light Detection and Ranging (LiDAR) through various machine learning classifiers.

Convolutional Neural Network (CNN) is used to create varied data set of building roof images on the basis of depth and roof shapes. The proposed method provides a high accuracy in identifying the roof tops as well as in improving the exactitude in the UAS rooftop landing. The architecture is based on the LiDAR and CNN.

The LiDAR data fuses with the satellite imagery with the help of various steps of machine learning classifiers to accurately identify the rooftops of the buildings. The collected data is processed to build the RGB and LiDAR images and further, this data is provided to the CNN for the feature extraction and to SVM to provide a single roof geometry result. [4][22][25][37]

A data of rooftops is collected from three cities by considering the roof shapes of different types like flat, unknown, complex-flat, gabled, half-hipped, hipped, pyramidal, skillion. For the CNN validation, a set accuracy LiDAR input image data in fully connected layer having the more accuracy then the RGB data input is considered. For the feature extraction, the LiDAR models are more effective with both SVM and random forest models achieving accuracies of 84.8% versus 84.4%. Keeping in mind, the wide use of LiDAR and CNN deep network, we have discussed it in the succeeding section. [4][5][37][38]

III. REVIEW LIGHT DETECTION AND RANGING (LIDAR)

Malcolm Stitch, the Hughes Aircraft Company introduced the first lidar like system in 1961. It was originally known as "Coherent Light Detecting and Ranging," (Colidar).It is a remote sensing method which uses light in the form of pulsed light to measure variable distances or range on the earth. These light pulses are combined with different information chronicled by the airborne system to produce detailed 3D information on the shape of the sphere and its surface characteristics. LiDAR data supports events like flood and storm surge modeling, hydraulics modeling, boundary mapping, emergency response, oceanography measuring, and shoreline vulnerability analysis. Where, MAD is Median Absolute Deviation, p-value is test's output. For the ground level, approximation and top elevation of covered area with data collected by Airborne Microwave Profiling Radar is used to measure the tree height and the forest structures.

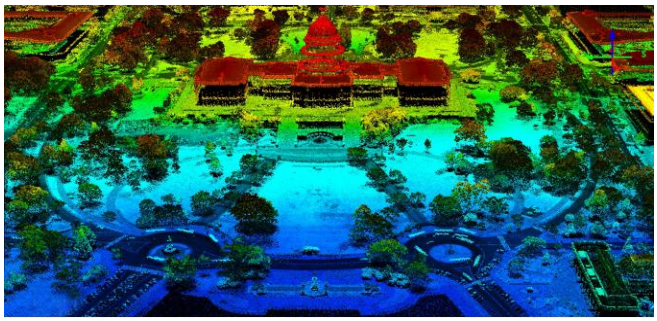

Fig. 3: 3D Lidar Point Cloud of the US Capitol Building in Washington, DC [31]

LIDAR Algorithm for filtering 3D LiDAR point [4]
Input: Collection of 3D points, A
Output: Filtered 3D point cloud, B

```
Z=A2
B=Ø
p-value = diptest (Z)
if p-value≥ .2 then
    MAD = median (|Zi – median (Z) |)
    for p in A do
        diff = |p2 – median (Z) |
        z- score =0.6745 . diff / MAD
        if z-score ≤ 3.0 then
            B=B+p
        end
    end
else
    B = A
end
return B
```

LiDAR is the best known method for estimating forest canopy height. For the evaluation of the accuracy, the digital terrain model and Velodyne VLP-16 LiDAR are combined with the Tomoradar system. [5]
The main focus is to estimate the distance between the canopy top or the ground and the radar system. The outcome of the study is Tomoradar is more accurate to identify the tree heights, ground level, and canopy top elevation with the root-mean square error (RMSE). [5]

A technique for calculating L band reduction by considering the canopies of the forest and focusing on the signal loss in the local forest with the help of canopy end values resolutes with hemispherical sky-oriented photographs (HSOPs). The output of the research is useful for predicting the performance of GPS and other microwave system related to the forests. [18]

The output of the research is useful for predicting the performance of GPS and other microwave system related to the forests. As compared to the LiDAR data, it considers SNR values and gives similar values but with higher RMSE. Also, it is rigorous and requires high level expertise. [18]

In the urban areas, LiDAR is used to check possibility of the GIS based system for estimation of solar energy and to support PhotoVoltaic energy production. For this by considering factors like active LiDAR, passive satellite or remote sensing methods in addition to the GIS models for estimating the energy from the sun or solar energy effectively. For the energy generation, it is considered building rooftops and the industrial areas in the urban region. [34][24][40]

It can also help to identify a single native tree types in a complex countryside using an object based classification method by combining the Quickbird image, LiDAR data and GIS model data. LiDAR is used to identify the tree heights and structure as well as identifying the ground conditions. [26] [37][38] The accuracy of canopy top with RMSE assessed using tomradar is accurate to 0.8m as compared to LiDAR. [5]. The prediction of the signal loss in the forest areas by photogrammatic measurements using HSOPs is effective as compared to the LiDAR for considering the signal loss. [18]. The method estimate for the PV potential form to roof top effectively by using the GIS techniques and LiDAR. [24] [41][51]

IV. CONVOLUTIONAL NEURAL NETWORK (CNN)

CNN is a deep learning algorithm to take image as an input and assign weights to the various objects which are present in the image and try to differentiate them from each other. It is a type of neutral network connected in the form of weighted graph structure. Multiple Convolutional Neural Network (CNN) architectures are competent and verified which provide a summarized feature set for support vector machine and decision tree classifiers with the best performing networks [4] [6]

A comparison of the 4 standard data sets with the help of diversity in Deep Convolutional Neural Networks (DCNN) and different types of fusion methods to classification of land cover and identification of objects in high quality electro optical remote sensing imagery has been given. As an outcome of comparison of PatternNet, RSICB256, AID, and RESISC-45 Deep Convolutional Neural Networks is done by evaluating classifier fusion technique which achieved 99.7%, 99.66%, 97.74%, and 97.30% accuracies. [6].

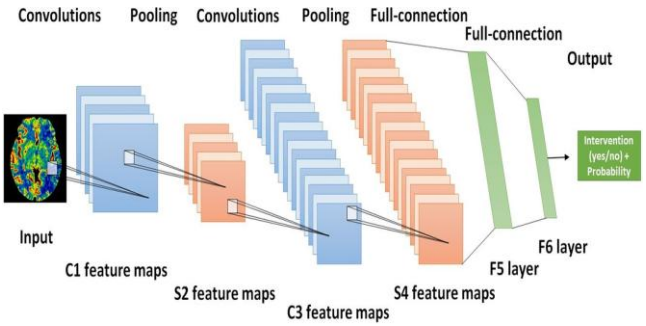

Fig: 4 Convolutional Neural Networks (CNN) [32]

Layers in the CNN used the covnets which are defined as the sequence of layers. Each layer passes data to another layer. There are different type of layers with different functionalities like input layer (holds raw input of image), convolution layer (calculating dot product of between all filters), activation function layer (apply element wise activation functions like RELU, sigmoid), pool layer (reduce size of volume for improving efficiency), fully connected (FC) layer (computer output as class scores and 1D array). [6][34][42].

Findings: Proposed is more effective and accurate to identify the building roof tops on the basis of depth and the roof shapes. It also improves the exactitude in the UAS rooftop landing.

Neural Network Pseudo code for calculating Output

- node[] := set of topologically arranged nodes
- An edge from p to q means p is to the left of q
- If CNN has I inputs and O outputs, then first I nodes are input nodes and last O nodes are output nodes.
- Incoming[n] := nodes connected to node n
- weight[n] := weights of incoming edges to n

For each element n, from left to right −

if n <= I: do nothing //input node

inputs[n] = [output[m] for m in incoming[n]]

weighted sum = dot_product (weights[n], inputs[n])

output [n] = Activation function(weighted sum)

V. PROPOSED WORK

The true power of GIS is analysis of data. GIS plays an important role in the spatial data analysis through which we can model the problems geographically. We can perform the GEO Spatial Data Classification using Machine Learning Approach for the identification of the roof top for Solar Panel System to identify the area which we can utilize for generating energy from the solar system and for the path hole management from which we would identify the road conditions at a specific location with immediate feedback to the concerned department for the necessary action by giving the images of the locations.

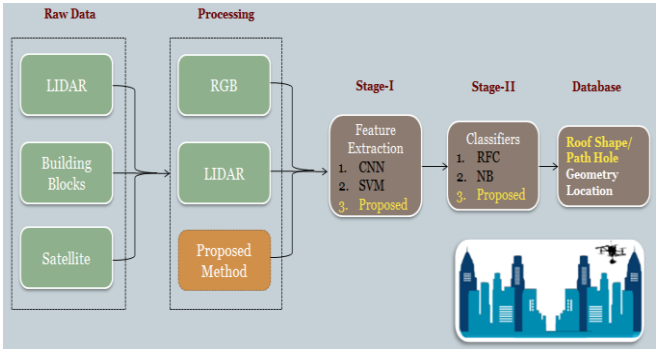

Fig: 5 Proposed System

For the proposed system, we would use the feature extraction techniques like Convolutional Neural Network (CNN), and Support Vector Machine (SVM) will be used for the supervised learning classification together with other classifiers like Random Forest classifier (RFC), Naïve Bayes (NB) classifiers for the comparison of data with our proposed system by using the machine learning approach. Approach is be to create image data based on GIS of Pune region and classify the various possibilities.

VI. EXPERIMENT EVALUATION AND RESULT ANALYSIS

Experiment was carried out on Window 10 OS, over Matlab Tool, on Inspiron I5 3000 series Laptop. Proposed system has unique technique to process raw data achieved through LIDAR, building blocks and satellite.

Dataset was collected by taking the google earth image over Pune city of India. Total of 9000 images was captured across the city which covers approximately 10,000 sq. mt area.

We have used Proposed Hybrid CNN feature extraction techniques for extracting the meaning full feature for detecting the roof top and calculating the area. Proposed algorithm is compared with SVM and CNN. Finally, the extracted feature is classified using random forest and NB classifier. Table 1, depicts the classification accuracy achieved using different classification and feature extraction techniques.

Table 1. Classification Accuracy Using Different Extraction Features Techniques

Input + Feature Extraction Techniques	Model	Test Accuracy
RGB +CNN	RF	76.5
RGB +CNN	NB	77.2
RGB+SVM	RF	74.3
RGB+SVM	NB	75.3
RGB + HCNN	RF	86.3
RGB + HCNN	NB	88.4
LiDAR + CNN	RF	85.2
LiDAR + CNN	NB	84.2
LiDAR + SVM	RF	85.3
LiDAR + SVM	NB	85.6
LiDAR + HCNN	RF	88.8
LiDAR + HCNN	NB	89.5

The above table depicts the accuracy level achieved on various combination of feature extraction techniques and classifier. It was absorbed that LiDAR techniques used with our hybrid CNN approach gives maximum accuracy in comparison to others.

VII. CONCLUSION

To conclude, the use of GIS makes the way for the future mapping of our valuable assets in an efficient way. Researchers have symbiotic roles to play in the advancement of geographic information system. Also, it will assist in the improvement of problem-solving skills and the decision-making process.

GIS based Intelligent Algorithms is used for the evaluation of the ships for the sea traffic safety but it is very time consuming and exhaustive process to run the simulation model of Agent based Simulation paradigm. So, there is a plan to apply hybrid modeling pattern to increase the simulation performance. [1]

It could be used for studying the various aspects of the earthquake disaster assessment like economic losses assessment, damaged buildings Assessment, and fatalities assessment. It would prove useful to analyze the GIS based quick examination of the field for helping the government for faster rescue operations. This is a local system and the results obtained by the system is not accurate and may lag to capture the exact data so the focus would be to capture more accurate and detailed data. [2]

For identifying the building roof top structure with existing GIS data by making fusion of satellite imagery, Light Detection and Ranging (LiDAR) through various machine learning classifiers, multiple Convolutional Neural Network (CNN), there is no standard data set for the identification of roof top. So in the future, automatically, detected inconsistent datasets for the automatic rooftop labeling could be beneficial.

We are planning to develop a model for rooftop identification with detailed and accurate data for the generation of solar energy and path-hole management to identify the road conditions in different regions with the immediate feedback of the condition of road to the concerned authority.

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