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Research Article

Novel Applications of Deep Learning in Remote Sensing Satellite Imagery: Natural Hazards and Disasters Risk Management

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ABSTRACT

The remote sensing satellite images based applications at worldwide has an important vision to implement and develop advanced space research technology usages and practically natural resources information and monitoring at local scales, district and national levels and provide correct inputs on time for an accurate disaster management and modelling e.g.: fire-forest assessment, floods, crop estimation, geomorphology, natural water resources information, urban changes etc. are simply carried out at high resolution spatial, spectral as well as temporal pixel resolutions. Remote sensing technology is effectively acquiring satellite-based information about the land surface, ocean and earth's atmosphere using advanced remote sensing-based satellites such as Sentinel series of Sentinel type-1, Sentinel type-2, LANDSAT's, Worldview -2, Worldview -3 etc. platforms. Remote sensing technology has widely used in military and civic usages. Accurate analysis of remote sensing satellite images is difficult due to the complicate nature of the satellite images. Development of suitable system for the accurate analysis of remote sensing satellite images is very essential. Traditional methods such as manual detection and identification of images and objects from remote sensing technology of the satellite images is very arduous, time consuming and costly. Advanced machine learning algorithms and remote sensing satellite images aids in various applications requires high resolution of spectral and spatial data / information includes agriculture, climate change, disaster management, ecology, environment, forestry, oceanography, transportation, weather, and so on. Machine learning algorithms such as Neural Networks (NN), Support Vector Machine (SVM), Random Forests (RF) etc. through advanced computer vision technology and deep learning algorithms includes CNNs, faster R-CNN, YOLO series to accurately identify and collect relevant features with actual accuracy and high speed.

Keywords: Remote sensing, Sentinel satellites, LANDSAT, Disaster Management, Environment.

1. INTRODUCTION: REMOTE SENSING

Remote sensing satellite imagery is the powerful technology of obtaining information, detection, analyzing, estimation, assessment, accurate monitoring the remote sensing based physical characteristics of coverage area by recording it is simply reflected and energy emission of radiation without making any type of physical contact with any surface or object under study.

Types of Remote Sensing: 1) Active Remote Sensing 2) Passive Remote Sensing.

LiDAR and RADAR both are best example of active remote sensing where LiDAR based on waves of light and RADAR based on radio waves, used for accurate object detection and monitoring. The photography, radiometers and infrared are examples of passive remote sensing. The passive remote sensors gather radiation that is reflected or emitted by the surfaces or object where sunlight refection is that is primary source of radiation that effectively measured by passive sensors. Passive remote sensors are most commonly used because passive sensors provide high quality of remote sensing satellite images. The passive sensors are important in the field of earth's observation including both Hyperspectral and Multispectral technology.

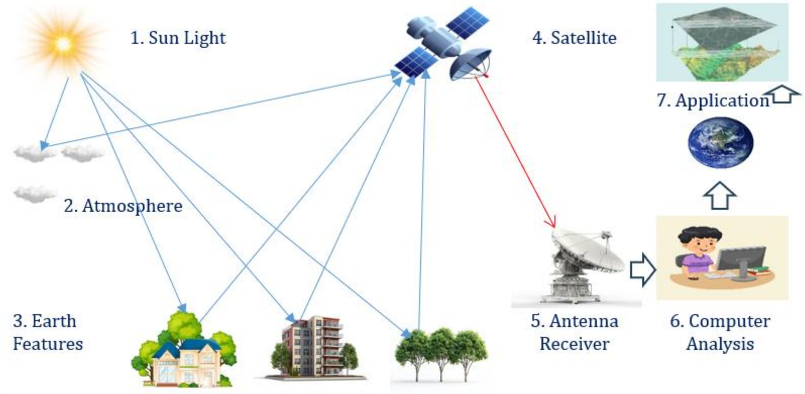


Figure: 01 Remote Sensing Process

1.1 Remote Sensing Satellites:

Table.1 Remote Sensing Satellites /Sensors

Sr. No	Name of the Satellite / Sensor	Specifications	Application
1	Sentinel-1	Sentinel-1's C-band	Earth's Surface Observation
2	Sentinel-2	13 Spectral Bands	Land Cover and Land Changes
3	Sentinel-3	21 Bands	Earth's Oceans, Land, Ice
4	Sentinel-4	Three Ultraviolet, Visible, Near Infrared, VIS and NIR bands	Monitoring of trace gas concentrations and aerosols in the atmosphere
5	Sentinel-5	7 Different Spectral Bands	Climate Change Monitoring and Air Quality
6	Sentinel-6	Ku-band, C-band	Sea-Surface Height Measurements
7	Landsat-8	11 Bands	Land use Planning and Monitoring
8	Landsat-9	Visible, Near-infrared, and Shortwave-Infrared Bands, and TIRS-2	Land change due to climate change, urbanization, drought, wildfire, biomass changes
8	Worldview-2	High-resolution Panchromatic Band and Eight (8) Multispectral Bands	Environment-Monitoring
9	Worldview-3	Eight VNIR Bands, Eight SWIR Bands, CAVIS (Clouds, Aerosols, Vapours, Ice and Snow) bands.	Wildlife Estimation and Assessment
10	GeoEye-1	Panchromatic and 4-bands	Disaster response, Air and Marine Transportation, Oil and Gas Exploration, Mining Production and Exploration,

2.REMOTE SENSING APPLICATIONS:

2.1) Flood Extent and Volume Estimation:

According to the information from the United Nations, about 90-92 % of all worldwide natural disasters are related to the floods. The Floods are among the most serious and unexpected natural disasters on earth. Their high intensity and occurrence rate that can have a significantly impact on especially in human and wild life, economy, infrastructure damage, risk of landslides, climate change as well as unpredictable effect on society of various flood affected regions [1]. The most common methods of flood monitoring are primarily based on site surveys, manual information, collection of aerial based images, which can be high cost, a lot of time taking as well as high risk tasks. In many situations, there is less possibilities of monitoring of flood extent in large coverage flood areas. To overcome these disadvantages of traditional methods, the remote sensing-based satellite images Sentinel type-1 Synthetic Aperture Radar (SAR) and Sentinel type-2 are more suitable for accurate mapping of flood extent events and reduce their effects on a global stage. The advanced deep learning algorithms has been widely used in flood extent management to improve the overall results of traditional methods for accurate flood extent and volume estimation mapping from remote sensing satellite images [2].

Figure: 02 Remote sensing satellite images of the floods affected areas, Rio Grande do Sul Brazilian state, 2024.

Table 2: Survey of flood events from 2020 to 2024 in the world.

Sr. No	Flood Event	Country	Date / Year	Death	Damage and Losses
1	Heavy Rainfall and Floods	Rio Grande do Sul Brazilian state	June 10, 2024	173	Caused: landslides in urban and rural areas.
2	Heavy Floods	Eastern Libya	10 September 2023	4,300	Caused: human health, schooling, safe regular water supply.
3	Floods	Pakistan	15 June to October 2022	1,739	Caused: Damage and economic losses
4	Flash Floods	European countries	July 2021	243	Caused : Insured losses
5	Monsoon season and Floods	Assam, India	October 2020	149	Caused: Damage to government building, road, bridges and schools

2.2) Forest Fires Assessment:

Forest fire is a vital and natural phenomenon in the degradation of the forest ecosystems and it is very difficult to control under the specific time. Forest fires are affecting the human lives and animal life, effect on climate, water cycle, soil erosion, air quality, biological and ecological damage etc. Nowadays, with highly increasing human population and urban changes, forests are endangered by both anthropogenies and wild area forest fires [3]. Normally, the forest fires have been classified into three types via, 1) Fire on ground 2) Fire on surface and 3) Fire on crown. About 91% of the forest fires in world are caused by human activities, huge deforestation and firewood burning etc. Thus, accurate forest fire monitoring and assessment is very important role in the world. The advanced remote sensing-based satellite images (LANDSAT, Sentinel type1, Sentinel type 2, Moderate Resolution based Imaging Spectroradiometer (MODIS), Visible Infrared Imaging Radiometer Suite (VIIRS)) plays a main role in accurate detection and assessment of forest fires burned and unburned area from high resolution satellite images with low cost and time saving technique. The burned areas are identified with the help of infrared bands along with the burned area and unburned area can be categorized separately [4]. The complete assessment of the forest fire and burned coverage areas are mapped by using 1) Burn_Area Index (BAI) 2) Normalized_Burn Ratio (NBR) and Mid_Infrared Burn Index (MIRBI) etc.

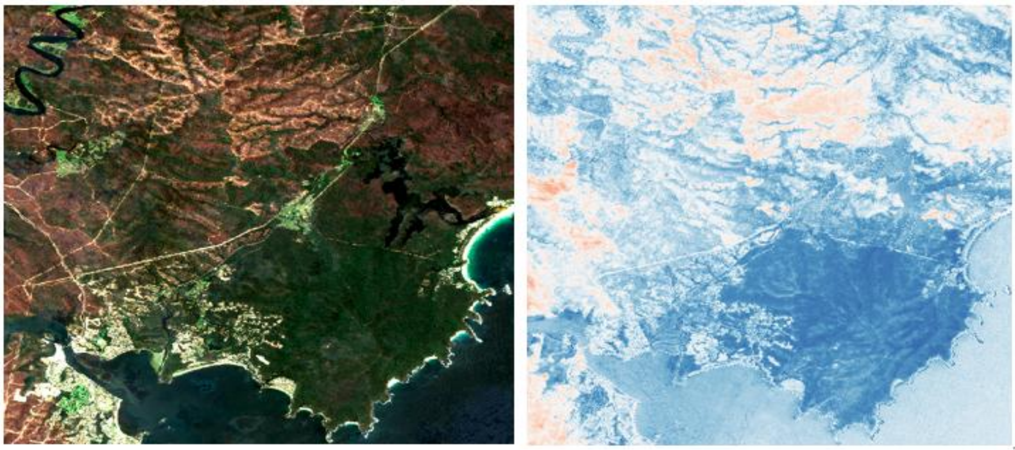


Figure: 03 Remote sensing satellite images of the a) Pre fire and b) post fire forest, Australia 2020.

Table 3: Survey of forest fires from 2020 to 2024 in the world.

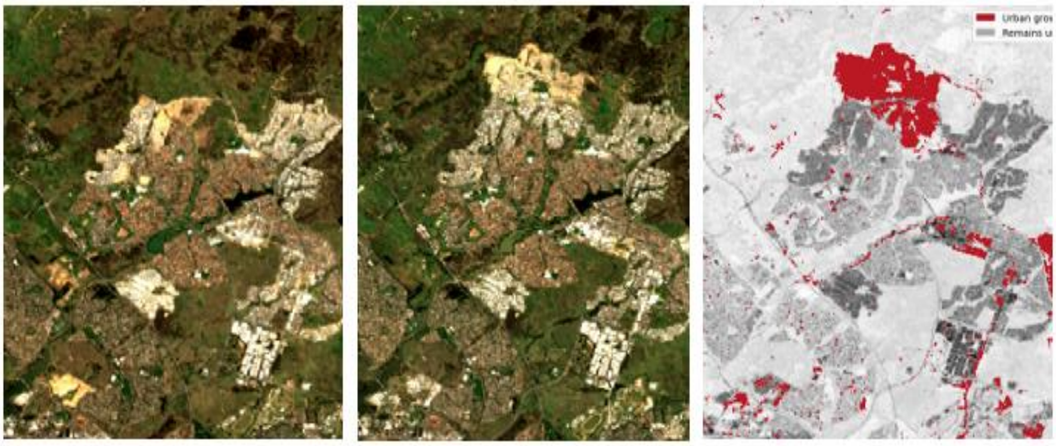
Sr. No	Forest Fire	Country	Year	Damage and Losses
1	Wild Fire	Bolivia, South America	2024	10 million acres of forest burnt
2	Wild Fire	Canada	2023	45.70 million acres of forest burnt
3	Forest Fire	Europe, Middle East and North Africa	2022	900,000 hectares of land burnt
4	Wild Fire	Algeria, North Africa	2021	100,000 hectares forest were affected
5	Bush Fire	Australia	2020	243,000 Square kilometres

2.3) Urban Change Detection:

Urban Change Detection (UCD) provides a complete information of urban areas expansion, reconstruction work as well natural disaster monitoring and assessment, by simply identifying the changes of ground surrounding objects according in different time slots. Previous, urban change detection techniques that were referred manual reports, field surveys as well as man made crafted processes to identify changes [5]. In the United Nations described that majority of the worldwide population lived in capital and urban areas in 2015, as well as two third of the worldwide population will live in urban areas in 2060. Remote sensing satellite images technology has been universally used to accurate estimation of urban change detection due to its low cost and time less observation. Urban change detection from remote sensing (RS) based satellite images that realizes the method of accurate and quantitatively identifying the changes of the surface from multi temporal satellite images. In the last few years, the advanced deep learning-based change detection monitoring methods has extensively increased since 2017. The LANDSAT and the satellite series of Sentinel type-1 and Sentinel type-2 satellite missions, simply combined with advanced deep learning techniques that provides new opportunities to accurate estimation of urban detection at a complete global scale [6]. The sentinel type-1, provides day and night images, all weather images at particular C band of various frequencies as well as Sentinel type-2 has 13 samples of spectral bands to collect a large geographical coverage data at resolutions of 10m to 60m, respectively.

Table: 04 Urban change detection (Year 2014 and Year 2020 Australian Capital Territory)

Sr. No	Characteristic	Description
1	Latitude	-35.1836
2	Longitude	149.1210
3	Baseline Year	2014
4	Analysis Year	2020
5	Location	Australian Capital Territory, Australia
6	Urban extent in 2014	33.6419 km2
7	Urban extent in 2020	39.7296 km2



a) Baseline Year=2014 b) Analysis Year=2020 c) Urban growth between 2014 and 2020

Figure: 04 Remote sensing LANDSAT-8 satellite images of the a) Year=2014 and b) Year=2020 c) Urban growth between 2014 and 2020 Australian Capital Territory, Australia.

2.4) Inshore Ship Management:

An accurate detection of inshore ships detection plays crucial role in harbour port management, port traffic management, fisheries management, transport applications, spread oil detection, military surveillance, etc. In last few years, the offshore ship detection in remote sensing images has been commonly considered while the detection of the inshore ship remains a complex and difficult task due to the surrounding complex background of the port, similar colour complexity, different shape and size of the ships along with different directions and scales, whether challenges and moored ships, the common traditional techniques of inshore ship detection is incapable to achieve an effective detection of inshore ships[7,8]. Example, when two or more ships are closed to each other and that have the same colour of both the inshore ships then it is more difficult to accurate detection of both inshore ships. Such a traditional method (Human Expert who find the all types of ships from visual based analysis) is a high cost and very time taking process along with cannot be effective at a very amount of large scale, while Sentinel type-1 and Sentinel type-2 satellite images (SAR) data provides a large amount of regular data along with worldwide coverage. Nowadays, the remote sensing satellite images (SAR) with advanced deep learning techniques are most significantly used in many applications such as military and commercial applications.

Table:05 Remote sensing satellites with deep learning techniques for inshore ship detection

Sr. No	Remote Sensing Satellites	Deep Learning Techniques
1	Sentinel type-1	Convolutional neural network (CNN)
2	Sentinel type-2	Region-based Convolutional Neural Network (R-CNN)
3	LANDSAT-8	Random Forest Classifier (RFC)
4	GF-3 satellite	Support Vector Machine (SVM)

a) Color similarity b) Weather Challenges c) Complex Structure

Figure: 05 Remote sensing satellite (Inshore Ships) images

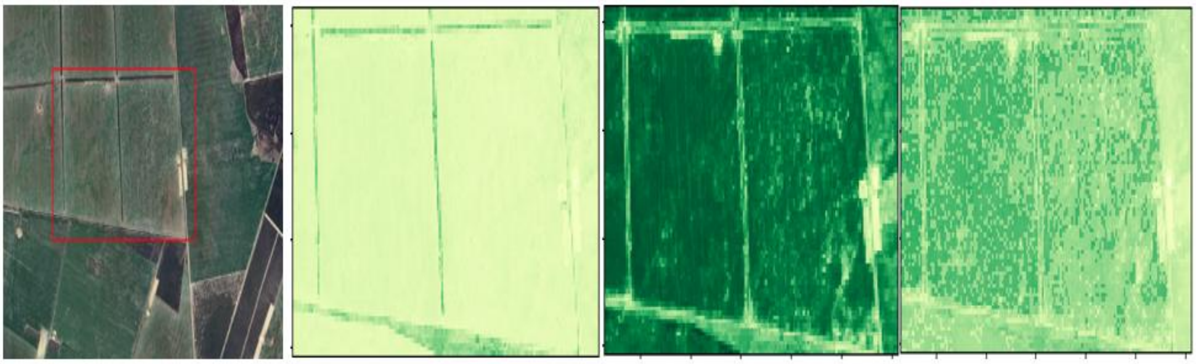
2.5) Crop Area Estimation:

The accurate estimation of crops and soils is very complicated because of highly robust and inherent complexness of biological contents and soils. The unexpected climate conditions and various other unpredicted environmental factors have a serious impact on the crop primary growth time and then on crop production [9]. The accurate evaluation of periodic crop production requires continuously monitoring of crop stages and conditions. In recent years, remote sensing satellite images techniques are most significantly applied in various agricultural applications such as crop separation, crop land estimation, condition of crop assessment, estimation of soil moisture, yield estimation and water management in agriculture. Nowadays, remote sensing satellite images technique provides several advantages compared to the traditional agricultural methods such as low-cost process, less time consuming, accurate estimation with fast survey, coverage of large agriculture land, high accuracy [10].

Table:06 Remote sensing satellites and sensors for crop area estimation.

Sr. No	Satellites and Sensors	Specifications
1	Rapid Eye Earth Imaging System	Rapid Eye has five spectral bands (Red band, Green band, Blue band, Red Edge and Near Infrared bands).
2	Sentinel type 2	13 Spectral Bands

3	LDCM (Landsat Data Continuity Mission)	Operational Land Imager (OLI) has 09 spectral bands and Thermal Infrared Sensor (TIRS) has two thermal spectral bands.
4	MODIS	MODIS has 36 spectral bands



a) Sentinel Type-2 Original Image b) NDVI at Start of Season c) NDVI at Peak of Season d) NDVI at End of Season

Figure: 06 Sentinel type-2 image with the life cycle of crops stages and conditions.

2.6) Oil Storage Tank Detection:

An Automatic detection and classification of oil tank in remote sensing satellite images play an important role in effectively monitoring of energy transportation as well as computation. The dense oil storage tank detection and classification activities have faced many challenges, such as color similarities, circular shapes and sizes of storage tanks, oil leaks, different direction and scales of oil tanks, complex surrounding background, weather forecasting, designing new cities etc. In previously, the traditional methods of oil tanks detection are mainly based on color, shape and texture information based on an advanced Hough transform, saliency map detection, image segmentation, image morphology and template matching etc. A high amount of remote sensing satellite images has been widely available and it is most commonly used in both civil and military applications. Remote sensing satellite images (SAR) has become an effective way to accurate detect oil tanks, which primary appear with circular shape features as in remote based captured images [11,12]. Remote Sensing satellite images with an advanced deep learning techniques Mainly (YOLO models) allows fast and accurate detection of oil tanks from complex infrastructure of surrounding background along with different scales and directions of oil storage tanks.

Table: 07 Four Deep Learning Models

Sr. No	Method	Four YOLO Models
1	Deep Learning based Models for Oil Storage Tank Detection	YOLOX
2		YOLOv5
3		YOLOv6
4		YOLOv7

Figure: 07 Remote sensing-based satellite images-Oil storage tanks dataset

2.7) Earthquake Damage Detection:

Unpredictable Natural disasters including sudden event of earthquakes is one of the dangerous geological disasters, which can seriously be affected on human lives, thousands of people die, infrastructure damage, economic damage, buildings and roads ruptures, crop production, water sources flowing unusual. Example, On February.06, 2023, as per turkey earthquake report, a 7.8 Richter scale (hit) earthquake occurred in southern area of turkey. According to the information, 57,000 people deaths, 108,367 people are serious injured, more than 240,000 building were collapsed, at least 10,700 buildings are partially damaged in northwest Syria. It is primary important to quickly and accurate detection of earthquake extent along with damage information. Remote sensing is an advanced technology for accurate detection of earthquake [13]. In the remote sensing, it has repeated acquisition of the satellite images of the complete earth surface in very short time periods as well as it has become easily to determine the earthquake extent and various changes in the land surface from unpredictable earthquake events through remote sensing bases satellite images. In recent times, the rapid development of remote sensing-based satellite images, the machine learning and statistical analysis methods have been extensively used in earthquake detection along with advanced deep learning models are widely used to the extraction of earthquake information which can highly improve the overall accuracy of earthquake identification and increase the efficiency of earthquake detection [14].

Table: 08 Seven CNN Deep Learning Models

Sr. No	Method	CNN_Seven Deep Learning Models
1	Deep Learning based Models Earthquake Damage Detection	4-layer Convolutional Neural Network (CNN)
2		AlexNet
3		ResNet152V2
4		DenseNet201
5		InceptionV3
6		Xception
7		InceptionResNetV2)

Figure:08 Remote sensing satellite images show buildings before earthquake (left) and after earthquake (right) in Turkey, February.08, 2023.

2.8) Climate Change Monitoring:

As per the UNESCO survey of “World in 2030”, the survey report focused that rapidly climate change is expected to be major issues in the next 20 years. It surrounds global warming, but mainly related to the wide range of differences that are happening to our earth, including greenhouse gases, surface temperature, shrinking level of glaciers, rapidly ice melt in Antarctica, Alaska and the Greenland; rising ocean levels; and extreme weather. Climate change is inherently linked and straightly threaten to economic damages have been mainly detected in living conditions, human and animal lives, public health care, agriculture land, natural water bodies, forest, fishery, tourism and coastal areas amongst others [15,16]. In the recent years, the advanced remote sensing technology has been widely used for effectively monitoring of the climate changes. It allows to monitor the land surface, ocean boundaries and the atmosphere at various spatio temporal based scales, that simply allowing different climate observations. Remote sensing Sentinel type-5 Precursor is the first Copernicus research mission mainly dedicated to effectively monitoring earth's atmosphere. The Sentinel type-5 Precursor carries the Tropomi based instruments that map a multitude level of trace gases, air quality, ozone level, climate monitoring.

Table:09 Remote sensing satellites for Climate monitoring and forecasting

Sr. No	Method	Satellites
1	Satellites for Climate monitoring and forecasting	Landsat -8
2		Landsat -9
3		Sentinel-3
4		Sentinel-5 Precursor
5		Sentinel-6

Figure:09 Ice melt in Greenland first image on14, June 2023 before (left) and second image on 14, July 2023 after (right). Image credit: NASA

2.9) Coastline Monitoring:

The sea coastline is mainly separating line between the sea and the land. The accurate coastal line monitoring is a main task in environmental protection and sustainable development. More than 50% of the world's population lives inside the range of 65 km from a sea coastline along with two-thirds of urban cities with more than 2.5 million population lives near areas of tidal estuaries. Nowadays, the global impacts of earth's climate change and rapid population growth, the major issue of geography changes in sea coastlines has become critical and more complex [17]. Therefore, the accurate mapping and assessment of sea or ocean coastline is one of the important factors for development of the new cities, urban planning and goals of sustainable development. In previously, two traditional methods are used to extract the coastlines: Field surveys and high pixel resolution based aerial datasets for analysis and monitoring from aerial collected images using standard software such as ArcGIS 10.3. Both traditional methods have common limitations such as high labour cost, time consuming, need technical experts, fieldwork safety issues and needs to be accurate statistical value [18]. To overcome these issues, the remote sensing satellite imagery plays an important role for effectively acquisition of both temporal and spatial data can be covered mainly from economical level of perspective. Remote sensing is a good alternative to extract coastlines using satellite imagery, this way both temporal and spatial aspects can be covered.

Table: 10 Remote sensing satellites for Coastline monitoring

Sr. No	Method	Satellites
1	Satellites for Coastline monitoring	Sentinel-1
2		Sentinel-2
3		Landsat-7

4		Landsat-8
5		Landsat-9

Figure:10 Effects of rising sea level on Coastlines first image on March 2018 before (left) and second image on February 2020 after (right). Image credit: Prof. Aurelio Mercado, Univ. of PR.

2.10) Smart Traffic Management:

Traffic management is a complex issue that is commonly present in all urban cities. With the rapidly increase of urban cities traffic and the essential to control it, the primary attention has been simply paid to advanced intelligent traffic control management systems, security and sustainability [19]. Traditional methods of traffic management, used as fixed surveillance cameras, traffic sensors, road detectors provide limited area coverage and fixed viewing angles. Many times, areas have been difficult to access due to similar color complexity, same type of vehicles, complex disaster, can be monitored. Currently, the urban city traffic is controlled by using all in one intelligent camera such as ANPR/ALPR which are mainly installed in road highways placed at an effective distance up to 120 meters from each other. With the development of ANPR/ALPR, this technology seems so accuracy issue, high installation cost, less security, regular maintenance and upgrades. Nowadays, remote sensing high resolution satellite images with advanced AI and deep learning technology (YOLO series) considered recently, the presence of an advanced intelligent system for particular road extraction and vehicle identification to control city road's traffic effectively with cost effective and high accuracy [20]. In remote sensing satellite images, maximum number of rural or city roads can be captured at the same time. Remote sensing new optical satellites such as IKONO and latest NAVTEQ have covered wide area images of the entire road network with 0.5-to-1.0-meter pixel resolution.

Table: 11 Remote sensing satellites for smart traffic management

Sr. No	Method	Satellites / Techniques
1	High resolution satellite images for smart traffic management	WorldView-2
2		WorldView-3
3		Faster R-CNN Resnet
4		YOLO Series
5		Sentinel -2

Figure: 11 Traffic management in the city of Vilnius, Lithuania, Europe. Original satellite image before (left) and traffic assessment image after (right) on January 2024.

3.CONCLUSION:

Applications of Remote sensing-based satellites imagery are very extensive. They have divided into two main areas. First, application in the entire earth observation, monitoring and process research studies of the complete earth system, and second application is operational applications. The previously can be divided into land, sea, cryosphere and their various interactions. In this paper, flood extent and estimation, fire forest, urban change detection, Inshore ship management, crop prediction, oil storage tank detection, earthquake assessment, change climate monitoring, coastline detection and smart traffic monitoring are described. This paper cannot include all various operational applications among them fisheries, oil spill, water vapor, ocean color, land changes and land cover, carbon cycle etc. With the highly pressure and limited storage of the natural resources due to the widely increasing world-wide population, remote sensing satellite imagery can be to manage these all-valuable natural limited resources in an effectively and useful manner. Remote sensing satellite data are quite useful in the accurate identification, monitoring and analysis of all these factors that mainly affect the usages of these natural resources. Lastly, remote sensing satellite data and methods have been widely used to effectively monitoring and assessment of disaster management and modelling

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