ANALYSIS OF DATA COLLECTION PARAMETERS FOR URBAN ENGINEERED SURFACES AND OBJECTS

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ABSTRACT: Detection and identification of targets involve the gathering of spectral signatures, which can uniquely determine the surface properties of the target or object under consideration. Availability of *a priori* knowledge which includes meta-data (latitude, longitude information, fore-optics of the sensor and environmental conditions) and reference spectra of the object, plays a crucial role in implementation of spectral matching and spectral anomaly detection algorithms. The spectra at a particular pixel is influenced by certain parameters such as illumination effects, height and background material, colour, material composition, surface geometry of object (slope, orientation and texture), age of material as well as atmospheric interactions. Therefore, for investigating the above parameters in order to interpret the *engineered surfaces* such as roads, bridges, roofs, sports infrastructure, railway tracks, monuments, water surfaces and *engineered objects* which are aircrafts, vehicles; an experimentation is being conducted to compare the spectra obtained in field under the effect of above parameters. The urban region considered for the study is Udaipur, Rajasthan located in western part of India. The site consists of diverse engineered surfaces and objects making it optimum for proposed analysis. This paper presents an analysis of various parameters which influence the spectra of engineered surfaces and objects in field and need to be considered during field data collection.

1. INTRODUCTION

Hyperspectral data is an amalgamation of spatial and spectral information represented in the form of a three-dimensional arrangement known as Data Cube, comprising of spectral vectors. Extricating all the pixel values of a particular spatial location, along the spectral dimension and plotting them as a function of wavelength catalyze the formation of spectra. Spectral signatures define characteristics of objects based on their absorptance, transmittance and reflectance of incident radiation falling on them [1]. Hyperspectral Image Processing extends its wide scope in numerous applications inclined towards land cover mapping, soil mapping, wildlife and forest management, natural disaster mitigation, military purpose and much more. The elementary requirement for implementing the foregoing applications is availability of precise Ground Truth which is an unbiased traceable representation of true value with an associated uncertainty [2]. It forms the foundation of preprocessing, computation, experimentation and analysis of many applications.

One of the major use of Hyperspectral Remote Sensing is for target detection purpose in order to perceive objects of interest in the scene. For this study, the targets considered are engineered surfaces and engineered objects, where an engineered surface may be regarded as a surface which is created artificially and has unique characteristic with some specific thickness to get a unique spectral signature. It may consist of either individual or multiple components (end-members) and can be considered stationary over a large span of time like roads, roofs etc. An engineered object may be defined as a physical body which is an identifiable collection of matter having a well-defined contiguous boundary which is visible or tangible surface of object. They can be stationary as well as mobile like vehicles and aircrafts. In hyperspectral target detection algorithms, targets are identified by examining the spectrum for every pixel which may appear as few pixels (full-pixels) or as part of single pixel (sub-pixels). Thus the whole problem revolves around, traversing all the pixels in the image on account of “target present” or “target absent”. The target detection algorithms can be grouped into two major categories, (i) Spectral Matching (ii) Anomaly Detection. Spectral matching algorithms depend upon *a priori* knowledge of reference spectra of target, which is necessary for its identification. The procedure involves comparison of reference spectra with all the spectral vectors present in the image in order to detect presence of the target. The reference spectra can be acquired either from any standard spectral library or from the image under consideration. An ideal spectral library is an encapsulation of preprocessed spectral database associated with metadata. United States Geological Survey (USGS), Santa Barbara Urban Spectral Library, ASTER spectral library, Johns Hopkins University (JHU) Spectral Library, Jet Propulsion Laboratory (JPL) Spectral Library are few of the standard spectral libraries available, populated with different types of targets [1]. Anomaly Detection algorithms exploit image segmentation mechanisms where each pixel is compared with local background (subset of an image) or global background (whole image) and, if the response of pixel under observation varies abruptly, then this pixel may further be considered to be part of a target object pixel [3].

As already mentioned, that a trade-off exists between the data acquired by field spectroradiometers and space or airborne sensors, due to difference in their scaling, data processing mechanisms, sampling intervals or quantization intervals, fore-optics specifications and scattering procedures of both the instrumentation. This gap between the readings can be bridged by *(i)* automating the process of maintaining the metadata *(ii)* conducting detailed analysis within the range of Instantaneous Field of View (IFOV) of spectroradiometers *(iii)* extending the storage space to handle spectral data and their corresponding metadata *(iv)* educating spectroscopy researchers to be cautious while taking the readings [2]. Therefore, consideration of certain factors is important while gathering the spectra. Based on literature, some of them are listed in Table 1:

Table 1: List of factors influencing a spectra of a particular target

S No.	Factors	Description	Parameters
1.	Sensor Related Factors	Sensors record the amount of light reflected from the surface of target corresponding to numerous wavelength intervals. The efficacy of the response depends upon following the necessary protocols of Field Spectroscopy. These factors can be taken care at the time of preprocessing, as few instruments allow to configure them according to the requirement.	Aperture size, focal length, focal plane array size, spatial resolution, spectral resolution, signal-to-noise ratio, radiometric resolution, calibration, Height and altitude of the instrument, calibration [4].
2.	Scene Related Factors	Targets confine to very small number of pixels in a scene, therefore content of the spectra is under influence of certain background features.	Material Composition, Color, scene complexity, (number of distinct surface classes) [4], Target Condition (open/hidden/camouflaged/ buried) [3].
3.	Atmosphere Related Factors	The behavior of electromagnetic radiation falling on a target is altered by absorption and scattering mechanisms of atmosphere, simultaneous corrections are required for correcting the distortions caused by atmospheric interactions.	Illumination, presence of haze, fog or clouds, Temperature, Moisture content [4].

4.	Spatial Factors	The spectral signature of a surface is highly dependent upon spatial features such as location and size of the target.	Target Location involves Surface, subsurface or Air whereas Target size includes Single pixel, a group of pixels or subpixel [3].
5.	Morphological Factors	Morphological features give a glimpse about the shape, boundaries, convex hull of a specific target.	Point, linear (line), Area (polygon).
6.	Processing Factors	These factors encompass their domain over the selectable attributes which can be varied in order to increase the accuracy of unmixing, detection, identification and classification of objects.	Threshold values, number of iterations, number of bands [4].

In order to validate the data acquired from airborne and space borne platform Ground Truth is necessary for additional analysis. Spectra of a particular pixel accounts to be a summation of interference from the atmospheric conditions, sensor noise, instrumental noise, background influence etc. Therefore, the assessment focuses on a detailed analysis of collecting the spectra of various objects in field, thereby providing chronicle order to create a rich spectral library initiating from gathering the ground truth till its analysis.

2. BRIEF REVIEW OF PARAMETERS

From literature it is evident that, the discussed parameters have a direct or indirect impact on the spectral signature of the target and can further distress its detection process. E.J. Milton et al. (2009), mention about the ideal atmospheric conditions with low water vapour and aerosol content for field spectroscopy. Therefore to minimise the hindrance posed by the atmosphere, an integral light source in instrument limits the size of objects that can be measured in regulated and controlled illumination conditions to inculcate precise detection of target. Major loopholes in process of spectroradiometry are also pointed, such as multidimensional nature of data, uncertainty in calibration of instruments and instability due to error minimization mechanism used [5]. Kriebel et al. discerned about the average change of reflected radiation with varying Solar Zenith angle and optical depth of atmosphere. At longer wavelength the change in reflected radiance increases a bit with increasing solar Zenith angle, which can be neglected And assume to be independent of wavelength. However, optical depth of atmosphere decreases with increasing wavelength [6]. M. Herold et al. investigated the spectral characteristics of urban surface materials and analysed their response with a comparative approach using Bhattacharya distance (B-Distance). Limiting the number of readings 25 each field target, 5500 reflectance spectra were gathered representing 147 unique services, which compiled to form Santa Barbara Auburn spectral library. The work focuses on analysing the spectral separability of urban target on the basis of grain size, material composition, structural features (surface roughness or smoothness) and geometry of the objects. It also provides a glimpse to identify the most optimum wavelength for mapping the targets [7]. Deepti Yadav et al. investigated the influence of scene parameters Namely illumination, background and colour for analysis of target spectra using spectral matching algorithms. The two targets considered were 100% polyester fabrics, of two colours red and blue. The experimentation results were not affected by the background which was taken to be grass and roof. For both background the targets were detected. The detection mechanism for target was obstructed due to Shadow, but blue and red fabric was detected in direct illumination conditions. No red colour target was detected by using blue colour's reference spectra and vice versa [8]. Yang et al. contributed in determining the best wave band to distinguish the camouflaged targets with background thereby detecting them bye spectral angle mapper algorithm [9]. Martin Herold et al. pointed out, the basis of accuracy assessment shall be confined till pixels rather than polygons. Also the work emphasizes the dependency of target spectra on location and size of the target. Additionally, the study suggested examining spatial and textural aspects of Surfaces and objects to overcome spectral similarities between specific classes, such as roofs and roads made up of asphalt [10]. Simou Adar et al. evolved an approach to categorise thresholding mechanisms into spectral domain and spatial domain. Spectral domain involved the analysis of parameters like sensor stability, atmospheric conditions and data processing variations whereas spatial domain georectification errors. The Experimentation concluded that, spectral domain thresholding offers high probability of target detection, however hybrid approach of spatial and spectral thresholding reduces the occurrence of False alarms. The study explains the comparative analysis of various thresholding methods available such as, Spectral Overlapping Threshold (SORT), Spectral Thresholding Approach for Registration error (STAR), automatic selection of decision threshold (ASDT) and Kapur’s Thresholding technique [11].

3. DATA COLLECTION

Data collection for hyperspectral remote sensing involves gathering the spatial and spectral data by means of satellite-borne platforms, airborne platform, field or laboratory instruments of same area under consideration. The method demands recognition of a specific site based upon the application to be performed. For instance, in order to analyze crop production, an agricultural site is required, for implementation of wildlife mitigation strategies, a suitable site including forest is the major source of inspection. The whole progression of collecting the data for various applications is briefed with the help of a block diagram (Figure 1).

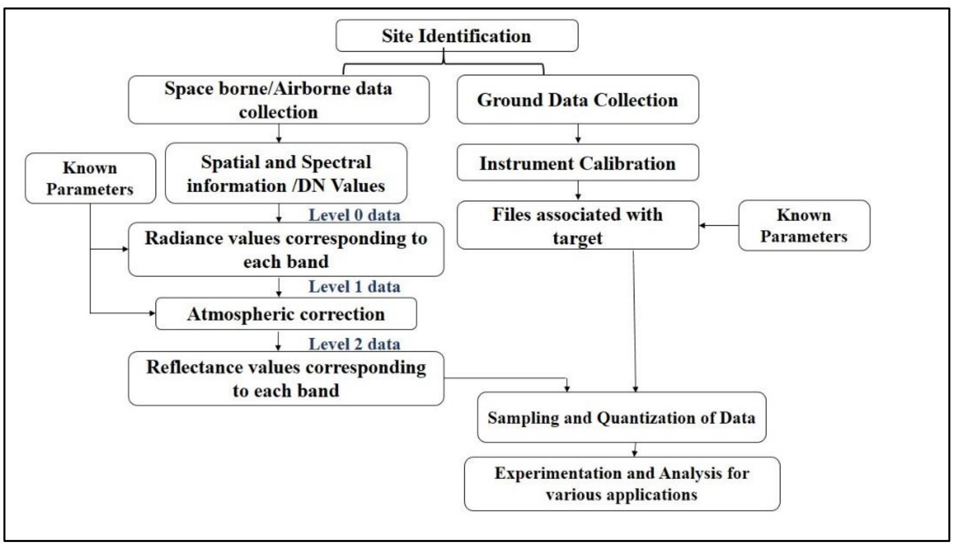

Figure 1: Block diagram of spatial and spectral data collection

3.1. Airborne / Satellite Data Collection:

The process requires HSI sensors to be mounted on aircrafts with well-defined flight lines over the area considered for investigation with *a priori* knowledge of date, time and altitude of flight along with solar elevation angle. The other relevant information that is required involves the fore-optics of spectrometer, number of bands, spectrally overlapping channels and ground resolution can be derived as a function ground level altitude and field of view. Artificial targets may be placed at known location to perform further experimentation.

Satellite data can also be collected but generally, have larger pixel size and less capability of band acquisition as compared to airborne data. It truly depends upon the location of satellites, that site under examination may be covered or not.

3.2. Ground Data Collection:

Field spectroscopic measurements are carried out by using an instrument called Spectroradiometer, with known spectral range (generally from 350-2500nm), bandwidth, spatial and spectral resolution along with scanning time. The setup includes calibration of the instrument with reference panel followed by recording of measurements with nearly constant height. Later the readings of digital numbers are converted into radiance and associated with metadata. Along with this, positional data is required which include latitude-longitude information of the object, which can be acquired by either handheld GPS receiver or Differential GPS. Other instruments such as thermal imager (to gather data in microwave region). LiDAR(for assembling 360^{o} view of a scene), cone-penetrometer (to record soil moisture) can be used as per the demand of the application. Additional software for storage of metadata may be advantageous in order to stock the data more quickly and conveniently.

3.3. Case Studies of various campaigns for construction of Spectral Libraries

Various data campaigns have been carried out in the recent past with the objective of finding out precise ground truth data for extraction of unknown information from hyperspectral data. Case studies being conducted give a summarised idea of data collection drives held for the purpose of target detection, identification, classification, anomaly detection and anomalous change detection. Case study 4 deals with the Interdisciplinary Cyber-Physical Systems Division of Department of Science & Technology, Government of India evolved a cluster based multidisciplinary Networked project on “Imaging Spectroscopy and Applications (NISA)” to promote research on various aspects of IS and its applications. This programme is also expected to evolve reference standards, protocols, database and research methodologies for adaptation in various fields relevant to society. This networked programme has 37 projects addressing various research problems (prioritized as per current need of the country and societal relevance) in seven theme areas such as geology, agriculture, forestry, water, snow and glacier ice, urban & built-in materials and algorithms. NISA also aims at developing four central laboratory facilities with sophisticated instruments in different parts of India to meet the scientific requirements and a centralised database management system for the storage and dissemination of generated data. As part of this venture, analysis of spectral signatures gathered is an important aspect to implement further applications.

Case Study 1: RIT Data Campaign

1.	Site Identification	Rochester Institute of Technology (RIT), Newyork, USA
2.	Data Collected	Hyperspectral, Multispectral, LiDAR
3.	Date of Collection	26th – 29th July 2010
4.	Objects/Targets	Open water, wetlands, urban environments (Fabrics, subpixel fabric targets, yellow cotton t-shirts, camouflage tarps, camouflage netting, cardboard boxes, vehicles, moving pickup truck, table, kiddie pool and black roof top)
5.	Airborne Data Collection	Instruments Used: i) ProSpecTIR-VS2 ii)Wildfire Airborne Sensor Program System iii) Lieca ALS60 LiDAR System Number of flight lines: 6 Solar Elevation Angle : 40^{o}
6.	Ground Based Data Collection	Instruments Used: i) Ground Thermal Imager ii) ASD FieldSpec Pro Spectroradiometer iii) Ocean Optics USB2000 Spectroradiometer iv) Tremble Surveyor’s GPS Device Ground Sample Distance(GSD) : 2m-3m
7.	Resources	i) Positional measurements: Latitude, longitude and height position. ii) Context photos of every target placed in field iii)Material reflectance of each target taken by ASD Field Spectroradiometer.

8.	Applications	Target Detection Blind Test, Dismount Detection, Physics-Based Target Detection, In Water Constituent Retrieval, RIT Wetlands Health Studies, Change Detection Experiment, Sub-Pixel Infrared Radiometry Experiment, Thermal IR Vehicle Tracking, LiDAR Target Detection
9.	Accessibility	http://dirs.cis.rit.edu

Case Study 2: Santa and Barbara Library

1.	Site Identification	Urban region of Santa Barbara and Goleta, located 170 km northwest of Los Angeles, California
2.	Data Collected	Hyperspectral
3.	Date of Collection	23rd – 5th June 2001
4.	Objects/Targets	Categorized into four-level hierarchy (Main class, subclass, material composition, color or texture) Land cover types, urban materials (urban built-up cover types such as roofs, roads, parking lots, sidewalks, recreational surfaces and landscaping elements), non-urban land cover types (water bodies, green vegetation, non-photosynthetic vegetation, bare soil)
5.	Space-borne Data Collection	224 AVIRIS band data Date of flight: 9th June 2000 Spatial resolution: 5m Spectral range: 370 nm- 2510 nm
6.	Ground-Based Data Collection	Instruments Used: i) ASD Full range Spectrometer (350-2400 nm) Spectral Interval: VNIR(1.4 nm) and SWIR(2nm) Number of bands: 1075 Field of View: 22^{o}
7.	Resources	i) Digital photographs of few urban targets ii) Location Coordinates iii) class names iv) Spectra names v) 5500 reflectance spectra, with 147 unique surfaces reduced to 108 (due to relatively rare abundance)
8.	Applications	Spectral separability of urban materials and land cover types, identification of most suitable wavelength bands in mapping urban areas, data analysis and image classification, database classification accuracy assessment, urban land cover classification
9.	Accessibility	AVIRIS Convolved Library

Case Study 3: Viareggio 2013 Trial

1.	Site Identification	City of Viareggio, Italy
2.	Data Collected	Hyperspectral
3.	Date of Collection	8th – 9th May 2013
4.	Objects/Targets	Categorized into a four-level hierarchy of scenarios (α, β, γ, δ) containing location and target. α: Parking lot in the suburban vegetated area (Vehicles, Panels, tarps) β: Parking lot, street, public garden (Vehicles, Panels, tarps) γ: Beach, sand dunes, Mediterranean vegetation, water (Panels, clothes)

		δ: Urban Downtown area (Vehicles) Several targets moved their position within scenario α, β and γ whereas other targets have changed their position while moving from α to β and vice versa.
5.	Airborne Data Collection	Elevations: 1200m and 450m Instruments: i) Pushbroom hyperspectral SIM.GA sensor ii) Panchromatic camera
6.	Ground Based Data Collection	Instruments Used: i) FieldSpec hand-held spectroradiometer (Spectral range: 350-2500nm, spectral resolution: 3 at 700 nm and 10 at 1400 nm & 2100 nm) ii) Differential GPS Lieca 1200 with accuracy of 2 cm
7.	Resources	i) ASCII and ENVI format data ii) Location file iii) Spectral reflectance of targets and calibration tarps iv) Change reference maps v) Imagery with different sky conditions(cloud cover, clear)
8.	Applications	Noise estimation and reduction, anomaly detection, anomalous change detection and spectral signature based target detection.
9.	Accessibility	http://rsipg.du.unipi.it

Case Study 4: AVIRIS NG

1.	Site Identification	Parts of states Orissa, Kerala, Tamil Nadu, Karnataka, Gujarat and Rajasthan, India
2.	Data Collected	Hyperspectral
3.	Date of Collection	2nd February 2016
4.	Objects/Targets	Agricultural land, Forests, Urban and non-urban areas, mountains, glaciers, water bodies.
5.	Airborne Data Collection	425 Band AVIRIS data
6.	Ground-Based Data Collection	Instruments Used: i) Ground Thermal Imager ii) Spectral Evolution Spectroradiometer iii) Cone-Penetrometer
7.	Resources	i) Location Details: Latitude, longitude and height position, locality, state ii) Environmental Details: Wind direction, wind speed, cloud type, cloud cover, temperature, humidity, sun altitude iii) Instrument Details: Sensor Type and fore-optics iv) Measurement Information: Spectral sampling v) Target Details: Background, texture, color, composition vi) Context photos of some targets placed in field vii) Reflectance of each target taken by Spectroradiometer
8.	Applications	Applications related to the field of agriculture, forestry, geology, material and terrain, oceanology, snow and glacier
9.	Accessibility	http://nisa.geos.iitb.ac.in/

4. ANALYSIS OF SPECTRA OF VARIOUS ENGINEERED SURFACES AND OBJECTS UNDER THE INFLUENCE OF VARIOUS PARAMETERS

The list of factors tabulated in Table 1 gives a glimpse of set of parameters influencing a spectral signature. The following comparative studies can be performed in order to improve the mechanism of target detection. Comparison of spectra with clouds and without clouds on the basis of wetness, by varying the height of instrument, oldness and newness of object, Comparison of spectra on the basis of fore-optics used (Contact Probe and Gun) and much more. The paper examines three criteria for comparison, namely, Spectra of a dry road vs. wet road, Spectra of an old bitumen road with a new Bitumen road and Spectra collected by contact probe and a gun.

4.1. Impact of wetness parameter on spectra: The presence of moisture decreases the reflectance values. Therefore in case of dry roads, Figure 2(a), signifies less absorption, thereby leading to high reflectance values from range 0.05 to 0.07. Whereas Figure 2(b) shows the influence of wetness parameter, by decreased reflectance values. As existence of water increases the absorption of incident radiation, causing reduced reflectance values.

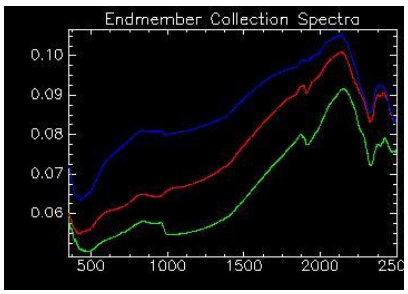

Figure 2(a) Spectra of dry road

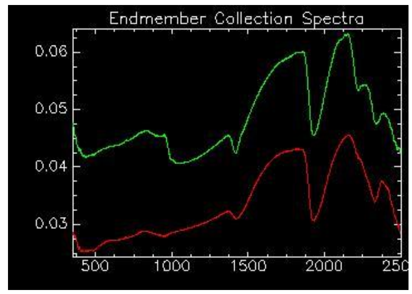

Figure 2(b) Spectra of wet road

4.2. Impact of age of material on spectra: As a material ages and its condition deteriorates, reflectance increases in all parts of the spectrum [7]. Absorption tendency of roads is reduced gradually due to accretion of dust and dirt on them. Another reason for this may be loss of greasing component from their surfaces. The spectral shape of road in NIR and SWIR changes from convex for new asphalt (Figure 3(a)) to concave for older surfaces (Figure 3(b)).

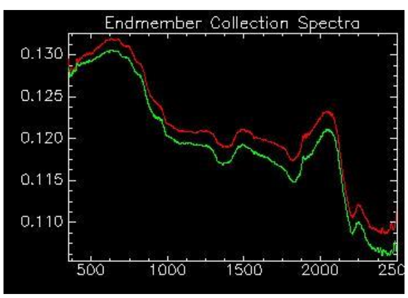

Figure 3(a) Spectra of New Bitumen Road

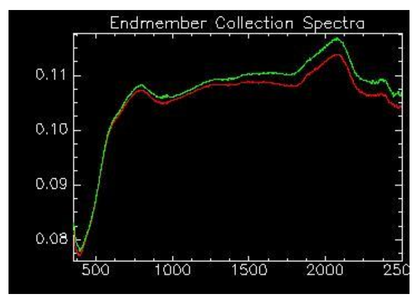

Figure 3(b) Spectra of Old Bitumen Road

4.3. Impact of source of light on spectra: Figure 4(a) shows spectra of vegetation, when readings are taken by contact probe, which shows fewer distortions. Due to artificial illumination source, the spectra appears to be more accurate and comparable with the standard spectral libraries. However, the spectra in Figure 4(b), whose readings are taken by gun, appears to be misrepresented under the influence of varying illumination conditions or natural sunlight. The interference of background material, atmospheric factors, varying height of instrument is greater in case of gun, therefore it leads to misinterpretation of detected objects.

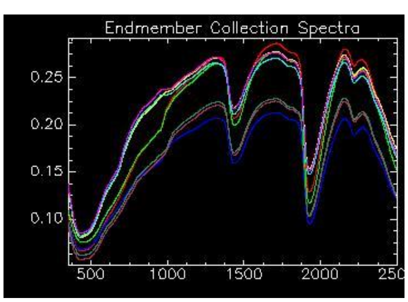

Figure 4(a) Spectra taken by a Contact Probe

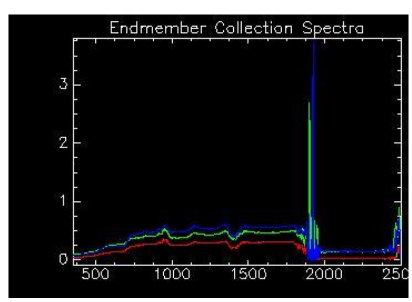

Figure 4(b) Spectra of vegetation taken by Gun

5. CONCLUSION AND FURTHER WORK

The analysis shows a comparison of the effect of wetness, age of material and source of light on various spectral signatures. If an object contains water as its composition, it leads to high absorption rate of incident radiation from the light source, which in turn reduces the reflectance values. As the operational period of a particular material tends towards completion with increasing time, the quality of the object or the surface depreciates, flattening its spectra. Varying illumination conditions may change the nature of spectra for a particular object under the influence of other additional parameters such as atmospheric conditions and background material composition, therefore it is suggested to take readings in controlled environment. The work can be carry forward for various applications like target detection, identification and classification of engineered surfaces and objects. Other parameters listed above can also be included for further experimentation which may lead to construction of a precise spectral library which can be used as a standard for the algorithms requiring *a priori* knowledge of data.

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