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SURVEY OF HYPERSPECTRAL IMAGING AND APPLICATIONS

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Abstract
The article deals with the survey of hyperspectral imaging and its applications. The article is devoted to a survey of the key areas in which hyperspatial imaging finds application. These areas include geological survey and mineralogy, plastic separation, food quality inspection, precision agriculture, landmine detection, medical imaging, and manufacturing processes. It can be stated that the possibilities where hyperspectral imaging can be used are numerous. Also, the application of such technology and its deployment needs a deep understanding of the problem to which we want to apply hyperspectral imaging. In general, it can be used where it is possible to compare images of the normal state against the current state with a comparison sample.

Keywords
Hyperspectral imaging, development, application, survey.

1. Introduction

Multispectral/Hyperspectral imaging, also known as a multivariate or spectral imaging, was first coined in the field of satellite and airborne imaging in early 1970's. It emerged from field spectral measurements in support of Landsat-1 data analysis [12]. The term itself made its way into scientific community in the late 1980's by the Department of Defense as they became interested in this sector and required a catch phrase [12]. The first definition of HSI was given as "the acquisition of images in hundreds of contiguous, registered spectral bands such that for each pixel a radiance spectrum can be derived" which is a precise definition of technique and according to the paper Evaluation of biological contaminants in foods by hyperspectral imaging: A review [26] it differs from MSI. When the promise of spectral image became apparent for the first time, the computing technology was not sufficiently developed yet, so there were not enough computing power and storage capacity to process such data [26]. Personal computer revolution in 90's solved this problem and opened hyperspectral imaging to the general scientific community. RSI company founded by David Stern in the end of 70's introduced Interactive Data Language (IDL). In the paper Three decades of hyperspectral remote sensing of the Earth: A personal view [12] it is stated that this language was used for the first time in NASA for data analysis and later in many other companies. The same is stated in paper An Introduction to Interactive Data Language [16]. In mid 80's by Joe Boardman and Kathryn Kierein-Young, the first hyperspectral image datacube was created which became the icon of hyperspectral imaging [12]. However, it took until mid 90's when ENVI software for processing of HSI was introduced for the first time to enable processing of more than 10 spectral bands see Fig. 1. ENVI was developed

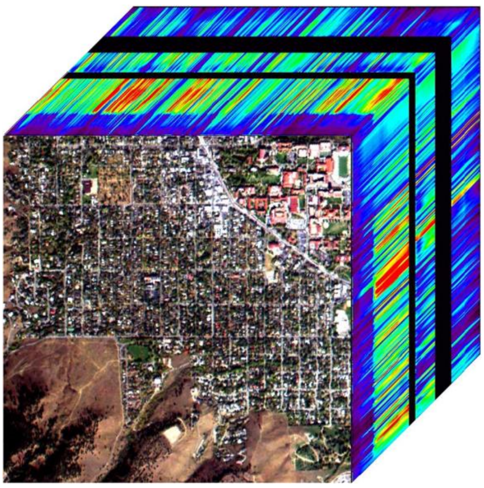

Fig. 1. Image that became the icon of HIS.

by the same company which created IDL, which became seamlessly supported across all computing platforms at that time. That led ENVI to become almost a standard, mainly in storing hyperspectral data. These are known in many publications as ENVI standard file formats, consisting of two files: one header, which describes how the data are stored and one binary file in which the data are stored.

In different literature publications, there are different views on what the Multispectral imaging or what Hyperspectral imaging exactly is. In the paper Multispectral vs Hyperspectral Imagery Explained [10] or in the paper Hyperspectral Imaging Enables Industrial Applications [27] the difference between multispectral and hyperspectral imaging is in a number of narrow bands which camera can sense, where for multispectral imaging it is up to 10 bands and for hyperspectral it is above 10 bands. On the other hand, in the paper Three decades of hyperspectral remote sensing of the Earth: A personal view [12] the authors see multispectral as non-continuous imaging of spectra (different bands can have some distance between them), where hyperspectral imaging should be continuous which means that between individual bands there are no spectral gaps or individual bands are overlapping. The multispectral imagining can also be seen as synthesis of imaging and spectroscopy. Data cube describing spatial and spectral information is the output of such a system. Usually, human eyes sense three basic colors (spectra) by cone cell in the retina. These colors are identified as red, green and blue, similarly as in general RGB cameras, which also sense in three wide spectral bands similar to those which human eye can see Fig. 2.

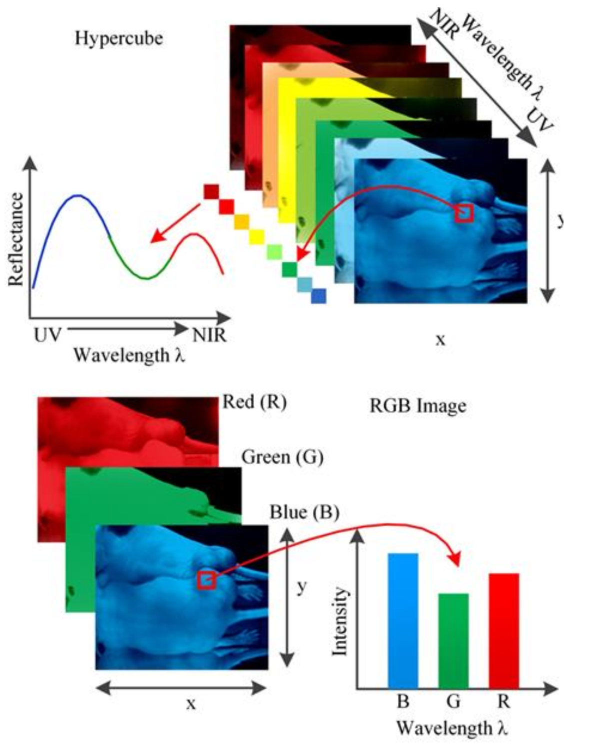

Fig. 2. Comparison of output from hyperspectral and RGB sensor.

Hyperspectral imaging is a unique and invaluable solution for a number of application areas. Remote sensing and geological survey were novelties in hyperspectral imaging. From that time, it has expanded into many other fields of science, military, healthcare, agriculture, waste processing, manufacturing etc.

2. Application of hyperspectral imaging

Application for multispectral/hyperspectral imaging could be divided into two main areas. In the first area remote sensing is used. This can be considered as all applications where satellite or airborne instruments use such as geological survey, mineralogy, precision agriculture etc. Secondly, there are stationary or handheld devices providing hyperspectral image such a medical examination, waste processing, food quality inspection and manufacturing inspection etc.

2.1. Geological survey and mineralogy

Geological survey and mineralogy can be dated back to the begging of the hyperspectral imaging. Since 1970s, it has been continuously used for geological mapping [21]. It was MultiSpectral Scanner onboard Landsat-1 that produced iron oxide maps or the first time. Later in 1982, Landsat-4 with its Thematic Mapper used band ratios to separate argillic from non-argillic materials and for mapping ferric/ferrous oxides. A new impulse to geological remote sensing was given by launching the hyperspectral sensor Hyperion on board of Earth Observing-1 [21]. This led to the publication of several new studies, which were focused on enhancing current technique of processing multispectral data and for evaluation of these sensors for geological mapping [21]. Hyperspectral mineralogy also found its way to space exploration on Mars Express and it is planned to place hyperspectral imaging system also on Mars rover 2020. We can say that geological survey and mineralogy is the main domain of hyperspectral remote sensing. This field also paved the way to other applications where remote sensing is used, like precision agriculture, military applications and many others. Application of hyperspectral imagining can be found not only in geological survey and mineralogy but also in derived products like plastics.

2.2. Plastic separation

Plastic separation, mainly due to environmental impact, which plastic represents in nature these days, is a frequently discussed topic. The studies range from using of airborne sensors to recognize plastic in oceans up to methods of separation of different types of plastic. Silja Bogfjellmo in his work Hyperspectral Analysis of Plastic Particles in the Ocean [4] proposes to use small, unmanned air vehicles equipped with mid-IR range hyperspectral camera to survey ocean for plastic waste. They were successfully able to distinguish plastic from salt water in simulated condition. Hereby the most successful method among the tested analyzing methods was SAM. In the paper Identification of bioplastics by NIR-SWIR-Hyperspectral-Imaging [15] the authors focus on the problem how to separate conventional fossil-based plastic from new "oxo-biodegradable" plastics and drop-ins by means of NIR-SWIR HSI. The problem is that these plastics are not distinguishable with a naked eye and they cannot be processed together. Therefore, the idea was to test if the push-broom NIR-SWIR HSI camera will be usable for this task and which chemo-metrical methods will be most suitable. The result of this study made fossil-based plastics distinguishable from oxo-biodegradable ones and proved NIR spectra is sufficient for successful identification. The second aim of this study was to distinguish drop-ins from fossil-based plastic also by the same method. However this was not successful and the authors of the study suggest extending the sensing range into MWIR and LWIR spectra. Hyperspectral imagining finds its application not only in inanimate objects but also in agricultural crops.

2.3. Food quality inspection

The issue of food quality and its safety increased in these days. As food becomes global commodity, since in many countries lots of food comes from abroad, the need for food inspection increase. According to Evaluation of biological contaminants in foods by hyperspectral imaging: a review [26], nowadays food inspection is mostly carried out in laboratories (evaluation for the presence of viable microorganism or toxins in food) or via sensory analysis. Hyperspectral imaging has potential for non-destructive, fast and economically favorable food inspection. As biological material decay, its chemical composition is changing and with that its spectral reflectance characteristics are also changing. It was successfully demonstrated that hyperspectral imaging system has the ability to determine a bruise in fruit and to provide quantitative and objective description of bruising. Laijun Sun and his team showed in their work The feasibility of early detection and grading of apple bruises using hyperspectral imaging: Early detection and grading of apple bruises. Tan et al. [24] showed that hyperspectral imaging system operated in spectral range from 401 to 1037 nm was able accurately recognize 99.1% of bruised apples (see Fig. 3). Moreover, they thoroughly characterized wavelength selection method, which combined competitive adaptive reweight sampling with correlation coefficient methods while support vector machine modelling was able to classify degree of bruising with 97.5% accuracy.

Hyperspectral imagining is applicable also for precision agriculture which improves the quality of products already in the growing phase.

2.4. Precision agriculture

Also known as satellite farming or site-specific crop management, it is defined as "a management strategy

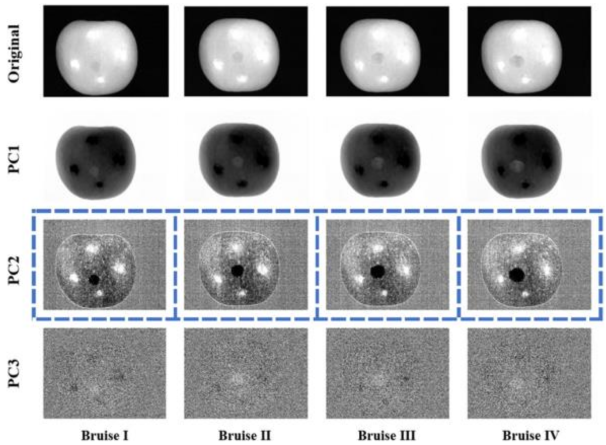

Fig. 3. Wavelength images at 950 nm and PC images obtained using seven characteristic wavelengths from the NIR spectrum region [24].

that uses information technology to bring data from multiple sources to bear on decisions associated with crop production" [17]. In works Precision Farming [6] and What Is Precision Ag? [1] it is stated that the precision agriculture, focuses on profitability, efficiency and sustainability on the farm. This is achieved though technology and equipment that can gather data about the water deficit, the amount of fertilizer or chemical needed and the maturity of crop. Stressed plants have measurable response in near-IR spectrum. This knowledge is exploited in Normalized Difference Vegetation Index (NDVI), see Fig. 4:

$$\mathrm{NDVI} = \frac{nir - vis}{nir + vis}, \tag{1}$$

where *nir* stands for near infrared spectrum and *vis* for visible portion of spectra [7].

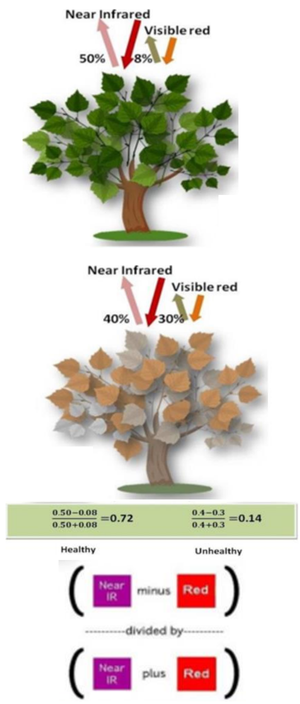

Fig. 4. NDVI calculation algorithm.

A healthy plant leaf absorbs the sunlight in ultraviolet and the visible part of spectrum very effectively. However, as it goes to longer regions of spectra waves, the reflectance and transmittance of the leaf increase dramatically which causes that absorbance falls to a very low value. This is due to the sun having the bulk of its energy in this region of spectra. If the leaf absorbed this energy with the same efficiency as in the case of visible spectrum it would become too warm which would cause denaturation of proteins [9]. From the above, we can deduce that healthier plants would have higher NDVI value. In other words, the closer NDVI is to 1, the healthier vegetation is in monitored area. And vice versa, the closer is NDVI to 0, the less healthy the vegetation is. From NDVI we can estimate vegetation water and chlorophyll content, stress tolerance, crop productivity etc. [17]. In civil sciences, hyperspectral imaging finds its application in several disciplines, such as landmine detection, which is described below.

2.5. Landmine detection

The war is a horrifying event for humanity in any time of human history, but it was in our era when consequences of war made people suffer long after the conflict ended. One of such remnants are landmines and booby traps. It is estimated that there are 110 million landmines in the ground. If the pace of mines removal is maintained, it will take over 1100 years to get rid of all mines on condition no new mines would be laid. The average price of removing one mine is around 300$ to 1000$. Facts about landmines [18] stated that if we removed all mines with existing technology, it could cost between 50–100-bilion dollars (see Fig. 5).

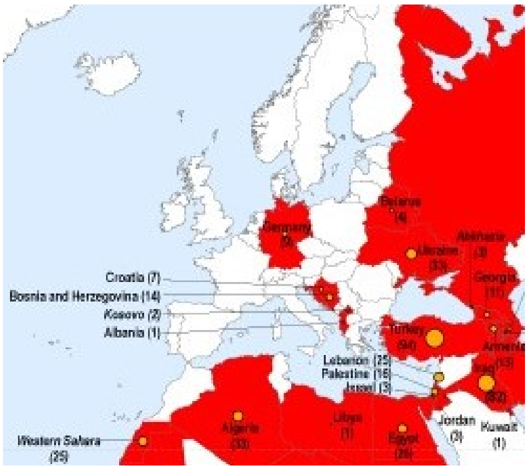

Fig. 5. Casualties of mines, explosive remnants and cluster submission in 2010 for Europe and North Africa.

It is necessary to promote new technologies for the detection of landmines to reduce the cost and to accelerate the pace of removal. Most of contemporary techniques are focused on detecting individual landmines [20]. Before any minefield begins to be demined demining operation plan must be created which considers the magnitude of the problem, the location of the minefield etc. This information is now gathered through interviewing the local population, former combatants and mine victims. Such a survey is time-consuming and information from them is often inaccurate. To speed up this process, researchers are focused on exploiting of hyperspectral imaging from airborne instruments that could offer reliable information about the position and the scale of minefield [20]. This will reduce the labor-intensive demining and will increase the cost efficiency because manual mine clearance will be led on a smaller area with the location of mines confirmed (Fig. 6).

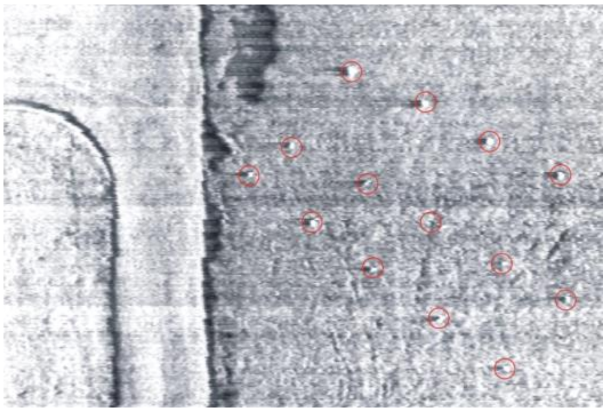

Fig. 6. Mines detected by airborne thermal IR remote sensing.

Similarly to mine detection hyperspatial imaging is applicable in medicine.

2.6. Medical imaging

HSI made its expansion in medicine, particularly in the field of non-invasive disease diagnosis and surgical guidance. Hyperspectral image provides diagnostic information on physiology, morphology, and tissue composition. When light penetrates biological tissue, it undergoes multiple scattering. There is an assumption that during progression of a disease light characteristics of tissue are changing. Therefore, we can assume that in the hyperspectral image these changes in tissue pathology will be rendered. In recent years, the complexity and price of hyperspectral imaging instrument have decreased which paved the way for many applications in medicine [19]. This is supported by an increasing number of studies on this topic. Skin cancer and its early detection is a frequently approached issue. There was study conducted of using Near-IR.

Fourier transform Raman Spectroscopy to diagnose malignant melanoma with 85% accuracy. Melanoma is characterized by marks such a color, shape and size. For untrained dermatologist it is especially difficult to recognize melanoma during visual examination [5]. However, there is a general consensus that tumor micro-environmental characteristics such as angiogenesis, hypoxia, apoptosis, blood saturation and tumor cell metabolism dictate tumor behavior [25] (see Fig. 7). There is intensive research of how to use this knowledge for better non-invasive in-vivo diagnosis of melanoma. In works Melanoma Diagnosis by Raman Spectroscopy and Neural Networks: Structure Alterations in Proteins and Lipids in Intact Cancer Tissue [11] and In vivo hyperspectral imaging of skin malignant and benign tumors in visible spectrum [5] it is stated that better early non-invasive diagnosis could significantly increase the chance for successful treatment and help avoid unnecessary surgical interventions, which could cause permanent damage on cosmetically important parts of body.

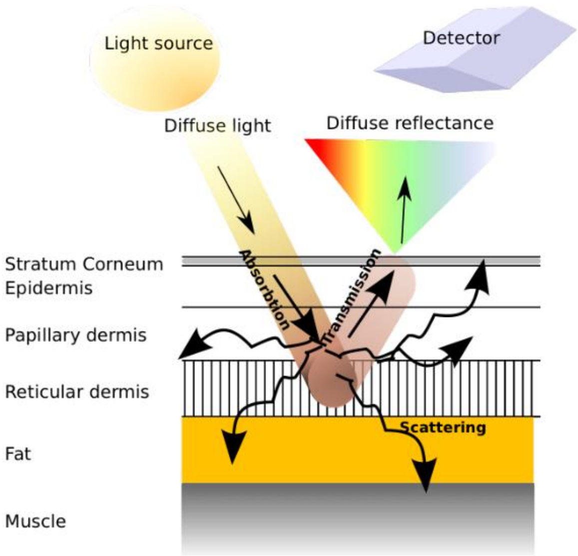

Fig. 7. Light path through skin structure.

The wide use of hyperspatial imaging also extends to industry, where it can be used in several ways.

2.7. Manufacturing

As in other areas, hyperspectral imaging is also used in manufacturing, with many works already published on this topic. It is mainly used in quality control, but it can also be used in maintenance to check the condition of the equipment and the wear of components and for the identification of conditions for reliable and safe production like company location and industrial waste storage. In general, it can be used where it is possible to compare images of the normal state against the current state with a comparison of what deficiencies could have occurred. For example, in the production of pharmaceuticals, hyperspectral imaging was used to check the composition of the granulate and also the output quality of the product in works Real-time determination and visualization of two independent quantities during a manufacturing process of pharmaceutical tablets by near-infrared hyperspectral imaging combined with multivariate analysis [22] and Practical issues of hyperspectral imaging analysis of solid dosage forms [2]. When checking the final quality of processing food, imaging was used in work Hyperspectral imaging – an emerging process analytical tool for food quality and safety control [13] and control of the quality of the battery in work Quality Control of Slot-Die Coated Aluminum Oxide Layers for Battery Applications Using Hyperspectral Imaging [14], the principle of comparison is shown in Fig. 8. The description of the use of hyperspectral imaging for maintenance is described in works Grading and color evolution of apples using RGB and hyperspectral imaging vision cameras [8] and Hyperspectral imaging applied for the detection of wind turbine blade damage and icing [23].

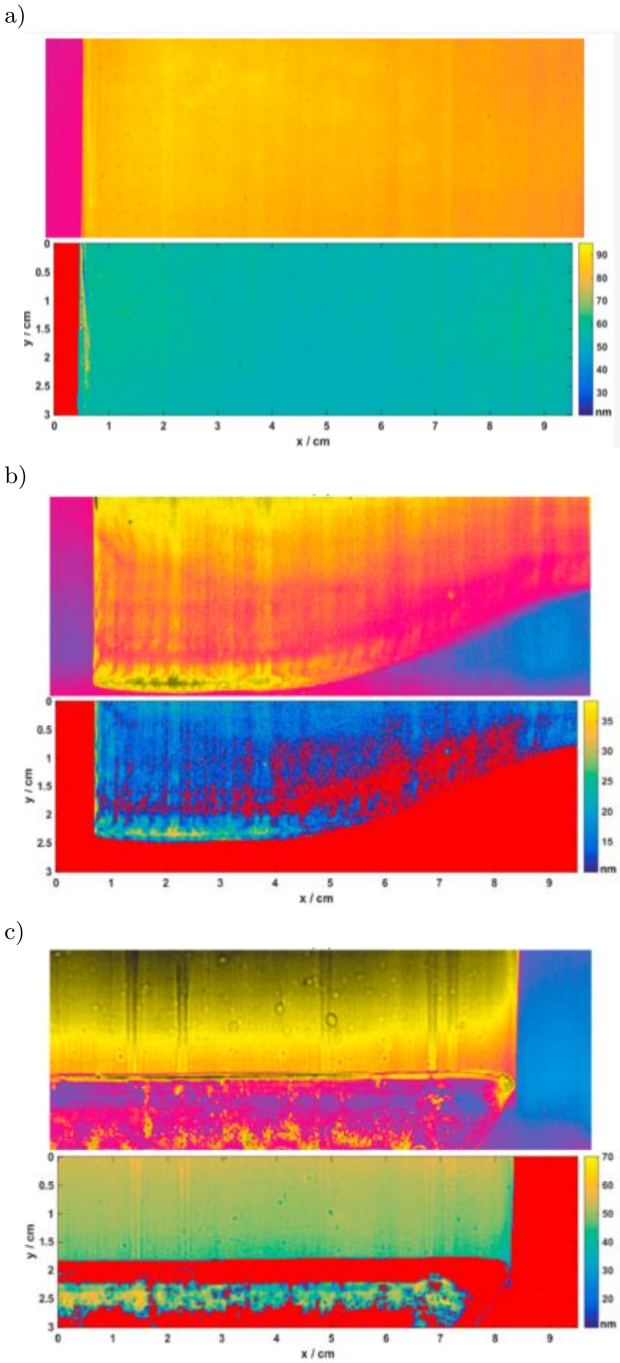

Fig. 8. Different samples for control batteries: a) nearly no defects, b) thin layer thickness and uncoated areas, c) coating defects and inhomogeneous layer [14].

As previously stated in sub-chapters, hyperspatial imagining is ideal tool for the identification of ideal ground conditions. For example, if a new plant is built, hyperspatial imaging can be used for the identification of places that are not waterlogged and which would not require investments to ensure the stability of the building as such. Also, hyperspatial imaging tools are useful when searching for ideal spaces for waste storage as well as for checking potential leaks.

3. Conclusion

As we showed up, the possibilities, where hyperspectral imaging can be used, are numerous. Precise preparation is an important thing on hyperspectral imaging. Every possible solution of involving the implementation of hyperspectral imaging needs deep understanding of the problem where we want the hyperspectral imaging to be used. We usually start with choosing a proper camera, so we should know in what spectral range we will operate. Depending on the behavior of the environment in which we will conduct hyperspectral imaging we must consider what acquisition technique is the most appropriate for us. The calibration of camera is an essential step because on it depends with what spectral radiation we will measure. At the end, the choice of proper software determines how we will process our multivariate data [3].

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