Decipherment of text on foxed documents by Hyperspectral Imaging utilizing the Video Spectral Comparator 6000

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Abstract: *Foxing is a process of deterioration that generates spots and browning on ancient paper documents such as books, monographs, postage stamps, certificates and other documents. It is believed that fungi and bacteria are the primary causes of foxing production. It is well known that physical, chemical, and biological processes degrade paper. Paper is especially prone to bio-deterioration processes due to its organic composition and hygroscopic nature; as a result, foxed paper becomes weaker, more fragile, and more acidic than undamaged paper. In circumstances where the text of a book or other document becomes unreadable owing to foxing, procedures must be established to make the content readable. In the present study, efforts were made to understand the unreadable text content of books damaged by foxing using the capabilities of the Hyperspectral Image (HSI) mode on the Video Spectral Comparator 6000 (VSC 6000) employing Near-Infrared Multispectral imaging analysis. This method optimizes spectral differences that are non-invasive. First, microbiological flora (fungal and bacterial) from old books were identified, followed by selecting the Video the VSC 6000 to conduct the research. As a result of the research, fungal foxing became decipherable with wavelengths ranging from 600 to 800 nm, and bacterial foxing at 645 nm following the above procedures*

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Keywords: Foxing, Video spectral Comparator, VSC 6000, fungus, bacteria, Hyperspectral Imaging

Introduction

Foxing of paper creates brownish-yellow spots on ancient paper documents such as books, monographs, postage stamps, old paper money, and certificates, as examples. In archives, libraries, and museums, microbes frequently degrade paper documents. Microbiological infection has been identified as a possible cause of paper deterioration (1,2). In circumstances where the text of a book or other document becomes unreadable owing to foxing, procedures must be established to make the content readable. Several investigations have identified the causes of foxing and discovered bacterial or fungal development on foxed sheets. In addition to metals, foxing has also been attributed to fungi and microbes. The degradation of paper can also be caused by physical, chemical, and biological factors. Due to its organic makeup and hygroscopic nature, paper is especially sensitive to bio-deterioration processes, and it becomes weaker, more friable, more brittle, and more acidic than the unaffected portion of the paper.

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Historical Context

The causes of discoloration and staining in historical documents can be as distinct as the materials used and storage conditions applied to them. For paper, a common symptom of natural aging is yellowing. Yellowing of paper has been attributed

Book number	Name of Book	Year of Publication	Name of publisher
F1	The complete guide to psychiatry and psychoanalysis, by Dr. Eric Berne	1947	Grove Press, Inc United States of America
F2	सब बिमारीयों की अत्यंत आसान दवाएँ लेखक बी एस दरबारी	1954	Sarvadhikar Prakashak
F3	Hurricane John D. MacDonald, Cape Fere	1957	Pan Book Ltd., 8 Headfort Place, London S.W.I

Table 1 Name of book and publisher with publication year

to photochemical reactions, which can be especially problematic for paper containing lignin (3,4). Missouri et al. (5) compared the optical spectra of ancient and artificially aged paper to show that discoloration in a paper may be the result of chemical changes in gelatin sizing that occur as a result of aging. Discoloration of paper used in historical documents can also be due to a type of stain known as foxing. Foxing is a well-known term used to describe stains that are reddish-brown to dark yellow (2,6–8). A wide variety of methods have been proposed to analyze foxing. Some studies reported the use of the spectroscopic technique to examine this problem (9–11) Buzio et al. (12) applied Attenuated Total Reflectance Fourier Transform Infrared (ATR-FTIR) spectroscopy and Atomic Force Microscopy (AFM) to study the chemical and physical properties of foxing stains.

Goltz et al (13) studied the enhancement of faint text using visible (420–720 nm) multispectral imaging and reported that single wavelength images from a nuance multispectral camera made it possible to distinguish the different inks that overlapped each other spatially. The iron-gall ink absorbed light at shorter wavelengths (<500 nm) and the typewriter ink had a broad absorption band that peaked at 620 nm. Single wavelength images at 620 nm were often sufficient for improving the legibility of the typewriter ink text on most pages.

For pages where the typewriter ink text was very faint, more advanced image enhancement approaches such as calculation of band ratios and principal component analysis (PCA) were useful for improving the legibility of the text. Imaging was carried out both in reflectance and transmittance mode, however, improving the readability of the text was most successful using reflected light. Authors noticed that it was largely due to the inability to properly flat-field the image when a transmitted light source was used.

In forensic investigations application of visible and IR, imaging has also been applied for distinguishing inks in fraudulent documents and currency (14). A hyperspectral visible imaging system for examining red, blue, and black inks was proposed in earlier literature (15). In a recent study, the feasibility of multispectral imaging has been enforced to examine the text of charred documents. Lin et al. (16) used a CCD array sensitive to IR interfaced with a digital camera for examining text on charred documents that were not legible in visible light. A variety of imaging techniques including IR luminescence used by Brown and Sin-David (17) for recovering text from a charred crew notebook that survived NASA's Space Shuttle Columbia. Non-destructive detection of iron gall inks using multispectral imaging was reported by Havermans et al (18). The authors used the FCIR (False-color infrared) method successfully for analyzing iron Gallo tannate ink in some practical cases. They identified the chemical quality of the script and drawing on historical documents although these documents were black to the naked eye and the quality of the paper was heavily deteriorated by ink corrosion. Chabrier, et al. (19) and Attas (20) used visible and near-IR cameras for enhancing the readability of text that was either faint or obscured. In the present study, we are reporting the decipherment of text on foxed documents by HSI using the VSC 6000.

Materials and Methods

The purpose of this study was to decipher altered text by using near-infrared multispectral imaging and luminescent photography of Foxing stains induced by a bacterial and fungal infection. Three distinct types of naturally aged books with black and brown

Fungi	Stain A	Stain B	Stain C
Aspergillus Niger	**(+)**	**(+)**	**(+)**
Penicillium spp.	(-)	(-)	(-)

Bacteria	Stain D	Stain E	Stain F
Arthrobacter spp.	(-)	(-)	(-)
Bacillus spp.	**(+)**	**(+)**	**(+)**
Micrococcus spp.	(-)	(-)	(-)

Presence (+); Absence (-)

Table 2: Fungal and bacterial species cultured (as mentioned in figure 1) from book pages

staining were acquired from a reseller book store in Nagpur and labeled F1 to F3 mentioned in Table 1.

The black colour stain [(Figure 1 (A) and (B)] was transferred to a perti-dish with Potato dextrose agar using the swabbing method with sterile cotton and incubated at 25°C for 5 days to characterize the stain. Similarly, using the scrapping procedure, brown colour stain [(Figure 1.3 (A) and (B)] was transferred to MYP (Mannitol-Egg Yolk-Polymyxin) agar substrate and incubated at 37°C for 48 hours. After incubation, black color stain [(Figure 1.2 (A) and (B)] revealed the characteristics of fungal growth showing a cottony appearance with black colour shown in figure 1, specifically Aspergillus Niger. A. niger's morphological traits were utilised to observe the colony. After 5 days of incubation at 25°C, A. niger colonies had diameters between 40 and 50 mm. The original growth was white and became black as a result of conidia with dark pigmentation. The colony's backside was a soft golden tint. Under a microscope, the conidial heads of A. niger were discovered to be big and dark brown. Conidiophores near the globule were black in hue. The conidial heads were biseriate brown in hue, but frequently had distinct metulae. The vesicles were round, dark brown, and had a rough exterior. (Figure 1).

The brown color stain (Figure 1.3 (A) and (B)] revealed the characteristics of bacterial growth, specifically Bacillus species. The plates were examined after incubation period for rough and abundant pink color colonies with waxy growth (1-4mm diameter) and irregular spreading edge. (Figure 1.1(A)

During sampling, a digital thermo-hygrometer was used to measure the ambient temperature (T) and relative humidity (RH). The books listed in table 1 were placed beneath the cabinet of the VSC 6000, and a near-infrared multispectral imaging analysis was performed. To create a digitally saved picture cube, a document can be examined in the VSC 6000/HIS mode throughout a wavelength range of 400–1000 nm at incremental steps of 1–20 nm.

The VSC 6000/HSI PC-based document imaging system, which consists of a main unit, PC system, and customized software, was used to conduct the HSI analysis. The document was placed on the document platen inside the main device, and the video camera was positioned directly above it, bringing the document into view on the PC monitor. The video camera has a maximum resolution of 2584 × 1292 pixels and uses both a high magnification lens and a motorized zoom lens. Incandescent filament lamps, which emit white (visible) light and infrared radiation to provide an overall range of 400 - 1000 nm, were used to provide flood illumination for IR absorption situations. Long pass filters were placed in front of the camera to examine the image in the IR range, and white light emitting diodes (LEDs) were employed to white balance the image. In HSI mode, a constantly variable band pass filter was utilized in front of a halogen spot light with a wavelength range of 40–1000 nm. Optical filters were inserted into the optical system's path to regulate the wavelengths of the illuminating light. Long pass filters allowed longer and shorter wavelengths of light rather than a specific cut-off wavelength value to illuminate the document for IR absorption/ reflectance (IRR) examination, whereas band pass filters allowed a defined narrow range or band of wavelengths between a long and short cut-off wavelength value.

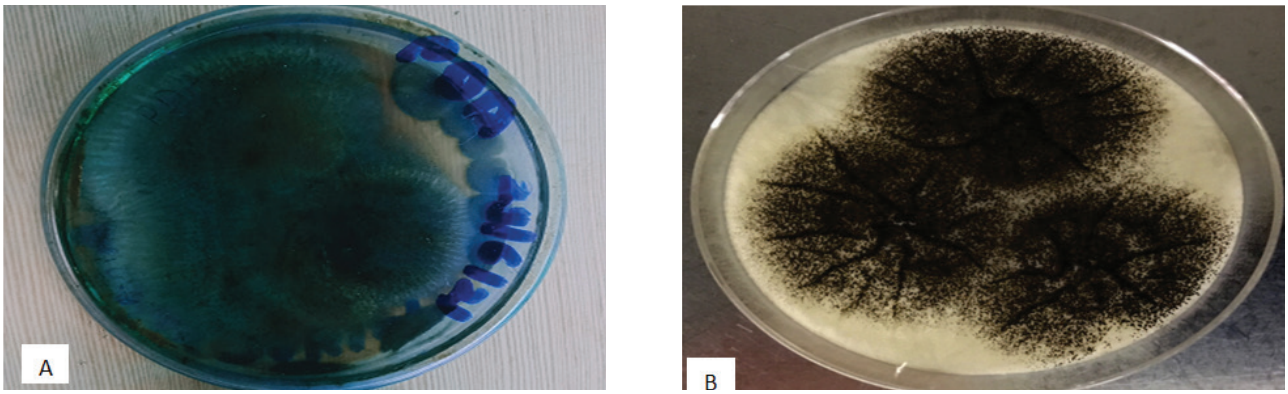


Figure 1 Characterized stains as Fungal Foxing stain and Petri dish showing characteristic growth of Aspergillus Niger

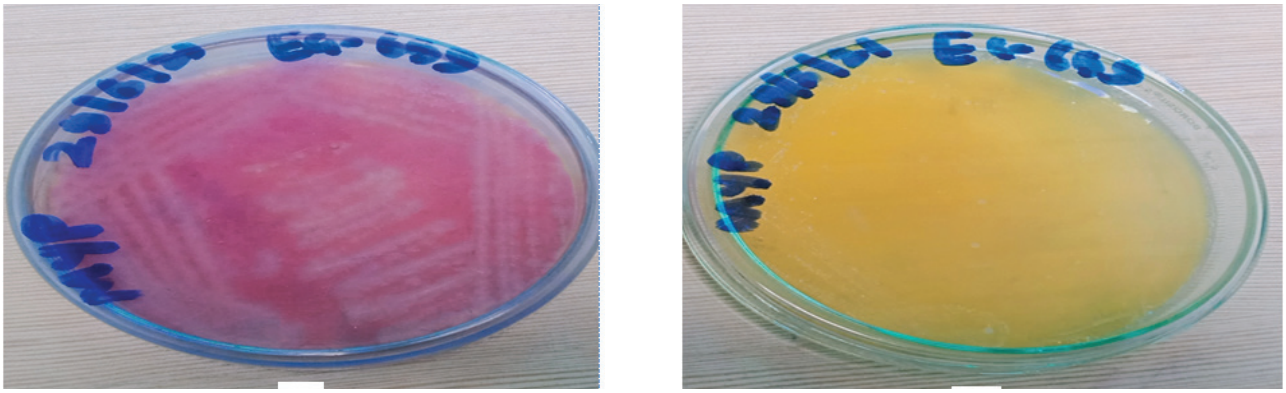


Figure 1.1 Characterized stains as Bacterial Foxing stain and Petri dish showing characteristic growth of Bacillus spp.

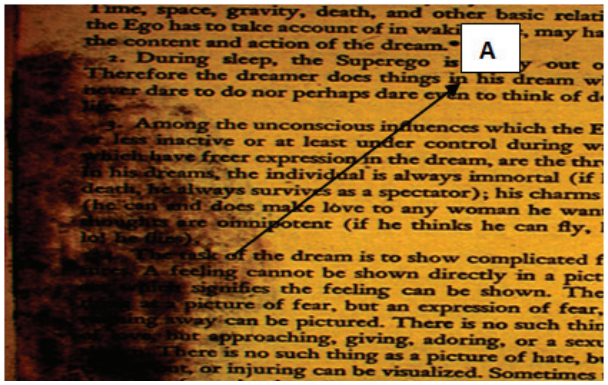


Figure 1.2 (A)

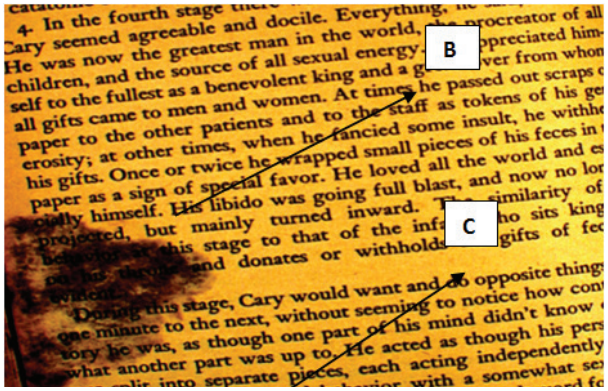


Figure 1.2 (B)

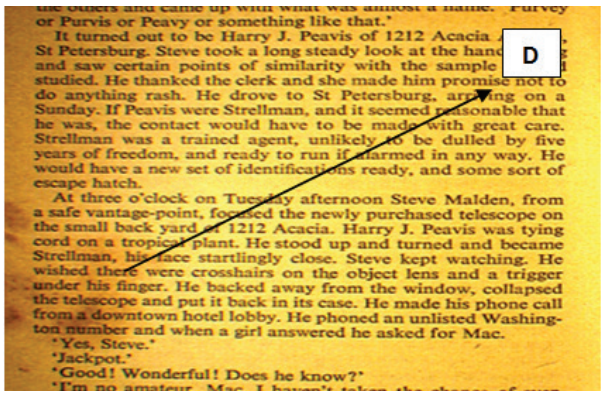


Figure 1.3 (A)

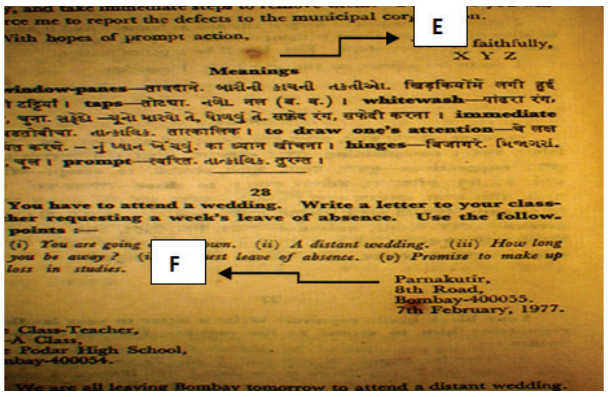


Figure 1.3 (B)

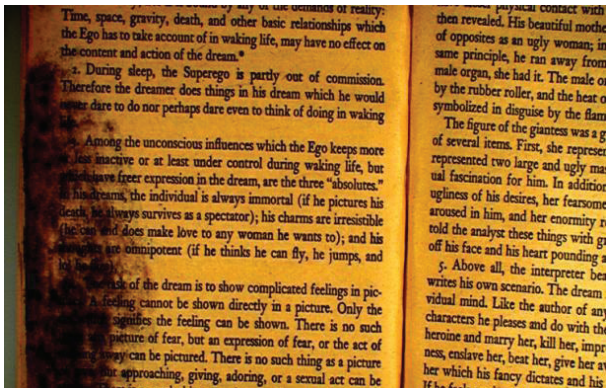


Figure E

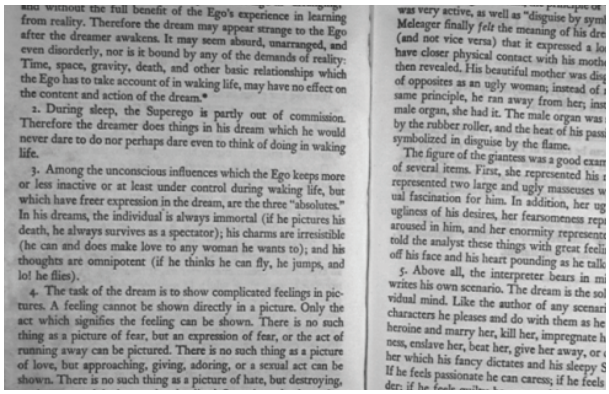


Figure E (1)

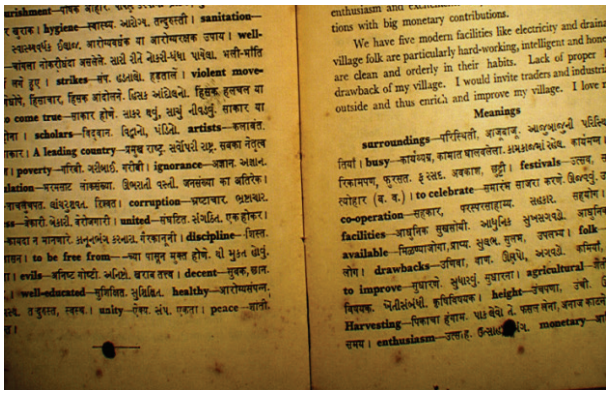


Figure F

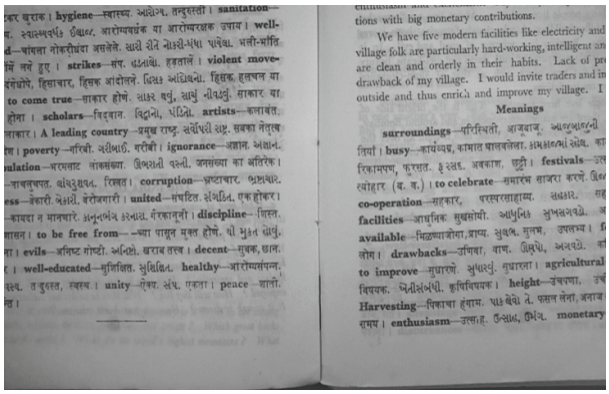


Figure F (1)

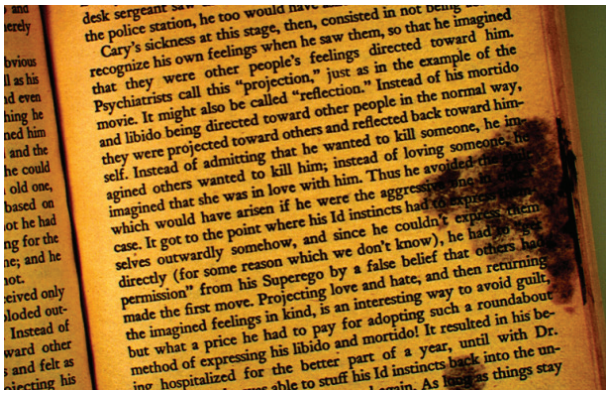


Figure G

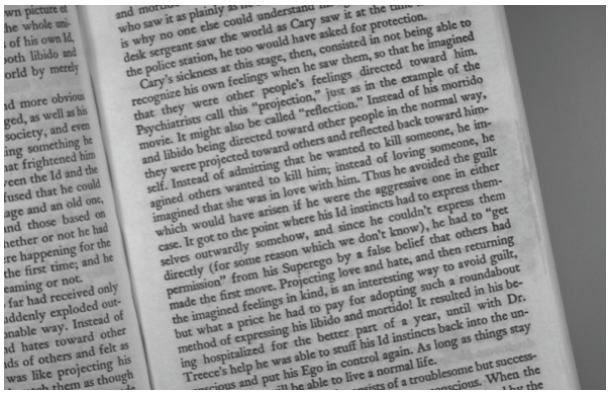


Figure G (1)

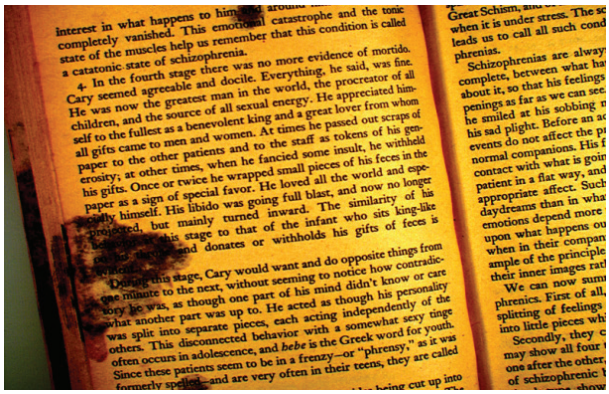


Figure H

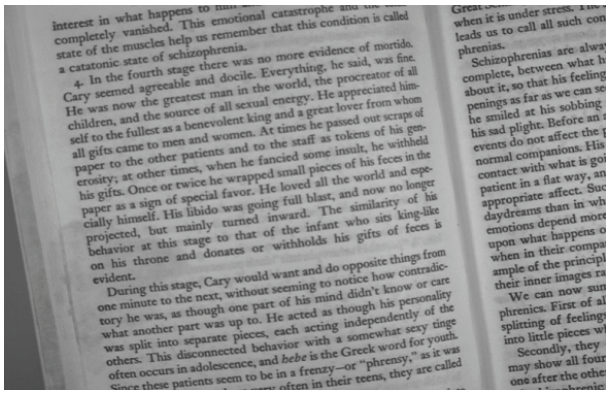
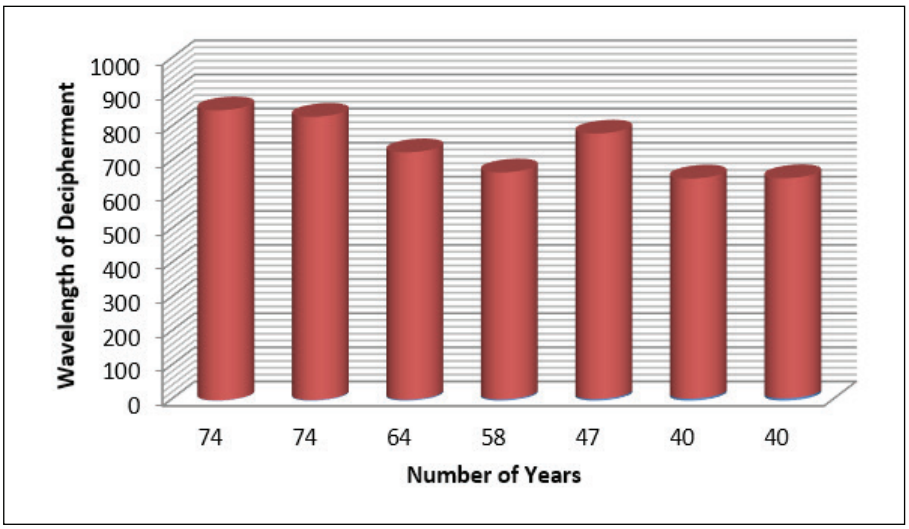


Figure H (1)



Graph 1 showing the decipherment wavelength decrease as decreasing year of book publication except notebook (5) (table 3)

Sr. No	Book Number	Total Year	Publication Year	Wavelength
1	F1	74	1947	850 nm
2	F1	74	1947	830 nm
8	F3	64	1957	725 nm
3	F4	58	1963	665 nm
4	F5	47	1974	778 nm
6	F6	40	1981	645 nm
7	F6	40	1981	645 nm

Table 3: The correlation between wavelength and year (Fungal Foxing)

The main unit's operation is managed by the VSC software, and each mode of operation is connected to a different working screen. Spectral and chromaticity data, for instance, can be examined via the spectrum screen, while live and saved images of the document can be viewed via the main panel, which also controls the VSC settings. With the use of the HSI mode, the VSC 6000/HS captures images of a document utilizing reflected light at certain, well-defined wavelengths across the spectral range of 400–1000 nm. An image cube, which may be replayed to see the wavelengths at which differences take place, can hold up to 150 photos at most. To produce enough imaging data throughout the entire spectral range, a band pass filter step width between 5 and 10 nm can be chosen. To compare any spectral differences within the document, spectral data from any specific pixel in the image can also be created.

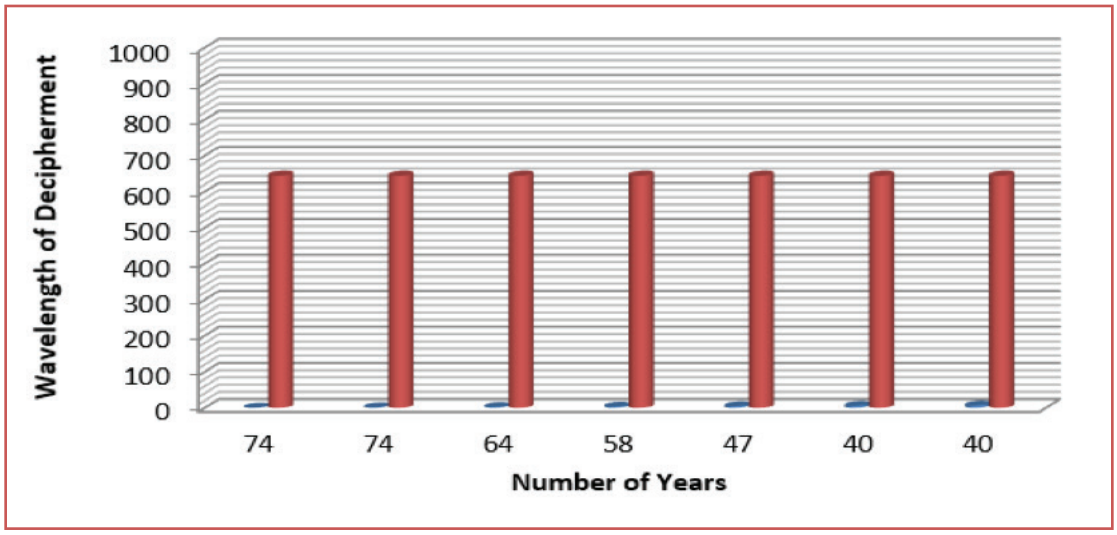
Results

The black color staining on the book shows growth of Aspergillus niger, and the brown color shows growth of Bacillus species (As per the result of laboratory test (Table 2, Figure 1 and Figure 1.1).

The Fungal Stains (FST) I and II contain black staining foxing spots with unrecognized text, while Bacterial Stains (BST) II and III contain brown spots with partially recognized text. The contaminated text is in altered form and needs to be deciphered with the VSC 6000.

Figure 2 shows the results of FSTs for seven older books on the left that contained foxing. On the right are images of the decipherment. Table 3 lists each of the pages by year and the corresponding wave length after the text became decipherableE

Correlation between wavelength of decipherment and year (Bacterial Foxing)



Graph 2 showing the decipherment wavelength at constant wave length

Sr. No	Book Number	Total Year	Publication Year	Wavelength
1	F1	74	1947	645 nm
2	F1	74	1947	645 nm
3	F3	64	1957	645 nm
4	F4	58	1963	645 nm
5	F5	47	1974	645 nm
6	F6	40	1981	645 nm
7	F6	40	1981	645 nm

Table 4: The correlation between wavelength and year (Bacterial Foxing)

Discussion

Due to foxing, the text written over the document is not readable with the naked eye. However, by utilizing the VSC 6000 and the HIS mode to decipher bacterial as well as fungal foxing, the text can become readable. The decipherment of foxed stain was possible at the wavelength of 645 nm to 850 nm shown in Table 3 and Graph 1.

The results show that the wavelength of the decipherment of the foxed stain is decipherable after the paper ages. In the case of bacterial foxing, the decipherment of foxed stain could be possible at constant wavelength (i.e., 645 nm shown in Table 4, graph 2).

In the present study, the results obtained after examination of all the foxed stains were encouraging and suggest ways to help document examiners in deciphering text damaged due to foxing.

Conclusion

In this paper, we have shown show how HSI, a function of the VSC 6000, is an effective method for assessing and deciphering foxed stains on the surface of aged books. The darkness of the foxed stain may be associated with the amount and the type of microbial contamination. A sampling of microbial (fungal and bacterial) flora from the old age book was carried out using non-invasive methods such as sterile swabs by wiping across spots and scraping stained areas with a sterile sharp-pointed instrument, by slightly rubbing over the investigated area. This culture is then used in culturing techniques to obtain in vitro growth of the microorganisms. The results indicate a correlation between fungal foxing and bacterial foxing, which leads to the conclusion that fungal foxing requires different wavelength ranges in between 600-800 nm

for the decipherment of text (Table 3), while in case of bacterial foxing; decipherment of text could be possible at 645nm (Table 4).

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In order to determine the nature of the stains, the books were submitted to Miss. Pooja Kathane, Technical Manager, at the Anacon Laboratory: FP-34/35, Butibori Food Park, MIDC Butibori, five-star industrial estates, Nagpur. They helped us for identification of the bacteria.

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