

# Outdoor Anomaly Detection with a Spectroscopic Line Detector

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**Abstract**—One of the tasks of optical surveillance is to detect anomalies in large amounts of image data. However, if the size of the anomaly is very small, limited information is available to distinguish it from the surrounding environment. Spectral detection provides a useful source of additional information and may help to detect anomalies with a size of a few pixels or less. Unfortunately, spectral cameras are expensive because of the difficulty of separating two spatial in addition to one spectral dimension. We investigate the possibility of modifying a simple spectral line detector for outdoor detection. This may be especially useful if the area of interest forms a line, such as the horizon. We use a monochrome CCD that also enables detection into the near infrared. A simple camera is attached to the setup to determine which part of the environment is spectrally imaged. Our preliminary results indicate that sensitive detection of very small targets is indeed possible. Spectra could be taken from the various targets by averaging columns in the line image. By imaging a set of lines of various widths we found narrow lines that could not be seen in the color image but remained visible in the spectral line image. A simultaneous analysis of the entire spectra can produce better results than visual inspection of the line spectral image. We are presently developing calibration targets for spatial and spectral focusing and alignment with the spatial camera. This will present improved results and more use in outdoor application.

**Keywords**—Anomaly detection, spectroscopic line imaging, image analysis.

## I. INTRODUCTION

**S**URVEILLANCE is a process that requires various tasks, especially in the case of military applications. The first task is constituted by (anomaly) detection. The environment is monitored and ‘anything out of the ordinary’ is reported. This may involve an object or even more basically a change in an otherwise constant background. The second important task involves classification, i.e. determining the nature and type of object, which typically requires more information than the detection task. Again more information is required for subsequent tasks such as identification of the object and/or further analysis of the activities. The detection task may need to be carried out continuously, more particularly with a sufficiently high frequency to allow for classification and further tasks and to timely prepare appropriate response if required.

Efficient surveillance requires good sensors of various types as well as good data analysis. In populated areas a crucial source of information may also be formed by human contacts. Radar and sonar are well known sensors for military surveillance, supplemented by other sensor types such as

magnetic-, vibration-, motion sensors, etc. Optical sensors, which have long since been a method of choice in civilian use are increasingly used also for military applications. They form a source of additional information for classification and identification but also provide detection of objects that are hard to detect by radar or sonar e.g. due to size or lack of signal reflection. Optical sensors are typically used in the form of video which is analysed by operators. However with the increasing number of sensors and the increasing cost of personnel and the need for automatic data analysis also increases, especially in the case of detection, which requires finding small anomalies in large amounts of data.

As may be understood from the above, detection requires searching for very small objects in the available data. Objects that may require attention should be detected with sufficient response time and will thus typically be small or otherwise hard to detect. In the case of optical surveillance the object may even be of sub-pixel size [1]. A certain amount of false positives is acceptable since these will typically be removed in the classification phase but not so many that the classification phase becomes clogged. A possibility to enhance the capabilities of a video sensor is the use of spectroscopic detection because it provides much additional information compared to standard colour imaging. Objects that may appear to have the same colour as the background may differ in spectrum or may have spectral features that help in detecting and identifying anomalies.

A spectroscopic imager provides a spectrum for each pixel that provides the response at a large number of wavelengths. These form a so called spectral cube. A range of algorithms is available to distinguish anomalies from the background [2]-[4]. Some require considerable computation time so that research is also done for economic algorithms for stand-alone or real-time systems [5], [6]. What algorithm is most optimal may depend atmospheric disturbance or background [1] or on the type of application that the detector is used for [6].

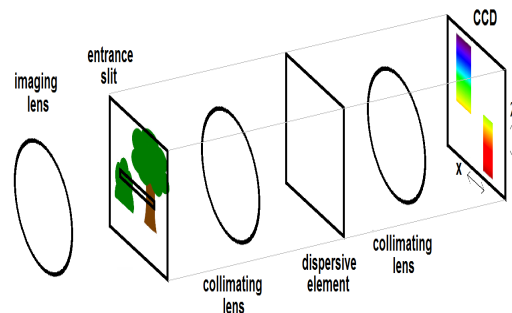


Fig. 1 Principle of the spectral imager

Several types of spectral cameras are currently used for the purpose of surveillance but these are quite expensive because of the difficulty of separating two spatial and one spectral dimension. An alternative is to make use of a simpler spectral line detector and modify this for outdoor detection. The basic operation the spectral line detector is illustrated in Fig. 1. A lens or other imaging system is used to image the environment onto the entrance slit of the detector. This slit admits a single line of the image into the detector which images the line onto the exit while a dispersion device such as a prism or grating is used to separate the wavelengths in a direction perpendicular to the line. Thus, each point of the image is separated into a line according to wavelength and the result is an image, which may be captured with a CCD that separates the spatial and spectral dimension.

Spectral line imagers are typically used in industrial applications, in a fixed assembly with objects reproducibly scanned underneath under controlled lighting conditions. Outdoor surveillance application requires for focussing and controlling light intensity and for aiming at a particular search area. In our research we use the SPECIM V8 spectral imager with a spectral range of 400-1000 nm and a slit of 9.8 mm x 50  $\mu\text{m}$ . Currently we use a fixed imaging lens focussed on infinity and a monochrome CCD that also enables detection into the near infrared. A simple camera is detached to determine which part of the environment is spectrally imaged.

## II. EXPERIMENTAL

Some typical results are shown in Fig. 2 with five colored magnets (3 cm diameter) attached to a white board at a distance of approximately 3 m. The area captured by the line spectral imager is indicated in the upper image. This was done by moving a ruler across the board until it was visible in the imager. In view of the aspect of the slit (1:200) the actual height of the captured area is probably considerably less than indicated. The area is approximately 40 cm wide so the height should be some 2 mm. It may however be more through blurring if the image is not entirely in focus. Lighting was done with a single lamp at some distance. Care had to be taken to have sufficient light for the camera without saturating the spectral imager. It was somewhat surprising that the imager was more sensitive than the camera even though the light is spread out spectrally. This is partially because a larger lens was used (2 cm vs 5 mm diameter) but possibly also because the monochrome CCD of the imager is more sensitive.

The line detector captures a line of almost 350 pixels wide and produces a spectrum for each pixel in vertical direction. The image shown is an average of 20 captured frames to reduce noise. The highest red object (the neighbor of the blue object) is not visible in the line detector image because it is outside (above) the acquisition area. The vertical lines in the camera image that indicate the width of the captured area are also visible in the spectral image which facilitates alignment. Their sharpness provides an indication that the image is in focus. In fact, it appears to be better than that of the imaging camera. However, that is due to the fact that the displayed

camera image is only a small section from a much wider image. The blurring is due to pixel size rather than focus. Whether the image is spectrally in focus is more difficult to determine, but this is likely to be the same.

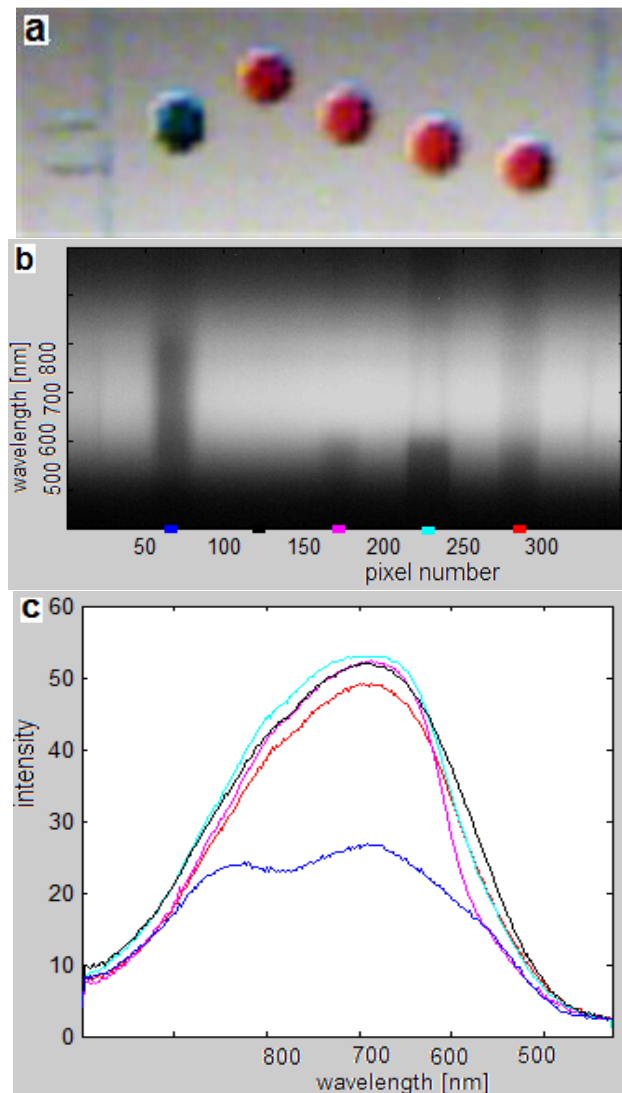


Fig. 2 Spectral line image acquisition with 5 targets: Green lines in the camera image (a) indicate the acquisition area for the line detector image (b) The five colors indicate columns from which spectra were taken (c)

Spectra were taken from the various targets by averaging columns as indicated. An average of 20 columns is taken for each spectrum to reduce noise further. The spectra of the red targets (red, cyan, magenta) are not so easy to distinguish from the white background (back curve). Mainly, the spectrum is darker for the lowest wavelengths (below 600 nm) and to a lesser extent at the higher wavelengths. Also the overall curves are not the same, probably because the light intensity differs in the different parts of the acquired image. This might be improved by normalizing the spectra, probably by acquiring

background spectra in the white areas of the board. The blue target (blue spectrum) shows a darker spectrum (it absorbs more light) and a clear peak around 840 nm (which may however also be a second order peak: 420 nm).

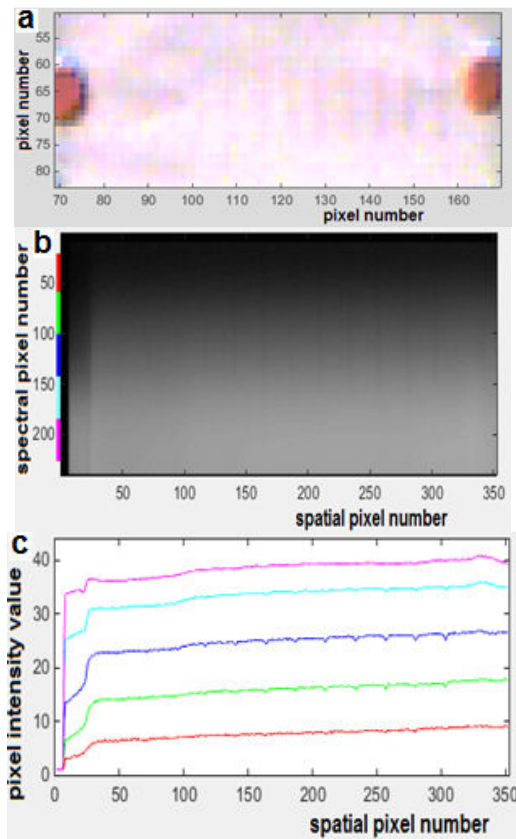


Fig. 3 Spectral line image acquisition with ten increasingly narrow lines on paper: Camera (a) and line detector (b) image as in Fig. 2. The five colors indicate spectral rows from which the spatial cross-section is shown (c)

For a first assessment whether our prototype spectral line imager is able to detect small targets, we conducted a second experiment was done using a paper with bright red lines on paper varying in width approximately from 5 to 0.5 mm (right to left). The last line is of sub-pixel size, even in the spectral image, which has some 350 pixels of a 30 cm wide area. Positioning and lighting conditions were the same as in the previous experiment. Results are shown in Fig. 3. The widest targets are visible in the camera image. For the narrow lines this becomes difficult. In the line detector image, more targets may be visible (dark lines) primarily due to the sharp transitions. This may be due to better focus.

A cross-section in various spectral region shows up to nine of small dips that can still be distinguished by the naked eye. Similar to the previous case 40 rows were averaged as indicated to obtain a cross-section. While the lines appear as quite black in the image the actual dips are quite shallow, no more than a few percent of the light intensity. The black appearance is due mainly due to our human perception of this

contrast. The dips are most visible in the center of the spectrum (blue curve). In the other spectral ranges the lines are indeed difficult to distinguish without further enhancement. A simultaneous analysis of the entire spectra may produce better results.

The lines of the cross-section are non-constant indicating a minor change of lighting conditions over the image. The lines show a large drop on the left side which is also visible in the spectral image. It may be due to a red magnet that was used to fix the paper and that is visible on the camera image. The changes are much smaller on the right side and the magnet may have been just missed there. It was not determined exactly at what height the image was acquired but as discussed above the acquisition area spans at most a few pixels of the camera image.

### III. ANALYSIS

For a better understanding of the detection in Fig. 3 we take a better look at the cross-sections and the line spectral image itself. For the former we zoom in to the cross-sections. Only a limited amount of zooming is possible since the background signal is not constant. A better zoom would be possible if this was removed. Nevertheless we now see that nine dips are easily distinguished in the blue and green curve (even the tenth may be visible on the blue curve). A number of dips also appear to be visible in the red and cyan curve but are more difficult to distinguish from the background noise. No dips are visible in the magenta curve which does indeed represent the blue part of the spectrum where the red target lines may not reflect differently from the background formed by the white paper.

As mentioned, a better analysis may be possible with a simultaneous analysis of the entire spectrum. This works with the assumption that there are only a few relevant spectra (here the background and the target) and that the recorded spectrum of each pixel is a linear combination of these. If the spectra are known their coefficients can be obtained by fitting the spectrum of that pixel and the presence of the target can be inferred from that. Typically, however, the spectra are not known. In that case the spectra and their coefficients can be estimated simultaneously with the help of so called singular value decomposition, a technique that fits the spectra of all pixels in the image with a minimal set of basis spectra. Unfortunately singular value decomposition does not provide a unique solution. Other sets of basis spectra can be formed with linear combinations of the original. It is easy to demonstrate that each of these sets provides exactly the same fit of the overall spectrum.

In the bottom panel of Fig. 4 we present a singular value decomposition of the line spectral image in Fig. 3. Since some artifacts occurred at the edges of the image we removed 30 pixels on either side and also 20 pixels from top and bottom of the spectrum. Instead of the basis spectra we show their coefficients for each of the 300 remaining pixels. The first five curves of the decomposition are shown, corresponding to the coefficients of five basis spectra. The upper curves fit most of

the curve while the lower curves fit mainly the remaining noise.

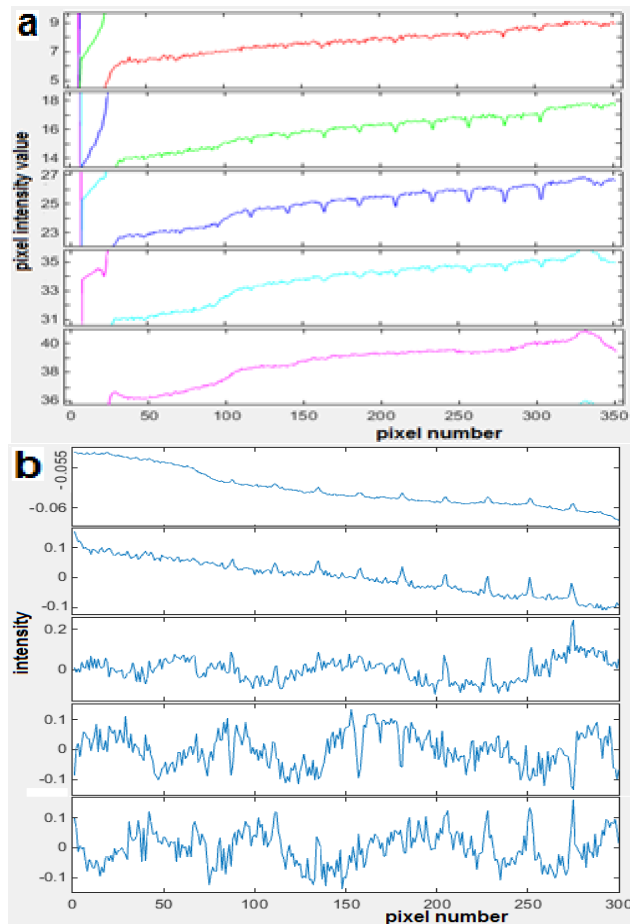


Fig. 4 Analysis of the image and cross-sections in Fig. 3: (a) zoomed-in copies of the cross-sections.(b) results of singular value decomposition

At first consideration one might naively expect that the first two curves in the singular value decomposition should be due to the background and the red target lines especially since we removed the artifact at the edges of the image. However, it can easily be seen that this is not the case here. The peaks corresponding to the target lines are visible in both curves and also in the others. Also, all curves except the first have negative as well as positive components. Moreover, the dominant background signal may change somewhat across the image so that more than one component is needed even for a proper fit of the background.

As discussed above the singular value decomposition does not provide a unique solution so that the actual curves can in fact be any linear combination of the ones that are shown. An efficient use of the singular value decomposition would require further processing of the components. This might be done for example by considering that the background will slowly vary across the image while the target signal will vary abruptly and in narrow intervals. Perhaps even more

fundamentally one might consider that the signals of the strongest components could be zero in some areas but should not change sign. By making linear combinations of the components with the above restrictions, more useful signals might be obtained. Nevertheless, the results in Fig. 4 provide some indication as to the enhanced detection that may be realized with such an approach. The peaks in the second component appear to be somewhat larger than even in the best cross section (blue curve) although the noise also appears to be somewhat larger. The lower three components show even stronger peaks but these may difficult to analyze since the peaks do not appear for all targets in the image while the background is also more variable. This is typical since these components do indeed likely originate from fitting of minor features in the background as well as in the target lines.

#### IV. DISCUSSION

In the present project we investigated the alignment and basic performance of a prototype spectral line imager modification for outdoor use. For this purpose it was adapted with a fixed lens a monochrome CCD camera and a small additional camera to monitor which part of the environment is being averaged.

As a first test we obtained images from simple targets at several meters distance from the detector which requires focusing of the imaging part of the detector and aiming at a relatively small acquisition area. The spectral characteristics could be roughly viewed and distinguished although a quantitative characterization of the reflection spectra would require much better characterization of the background illumination. Furthermore, we tested the ability to distinguish targets of various sizes from the background. These could indeed be distinguished in some areas of the spectrum but a better signal enhancement or analysis will be required to detect targets of subpixel size. This may be achieved for example with a simultaneous analysis of the entire spectral image.

To detect potential anomalies in a signal one typically estimates the background signal, i.e. by fitting a polynomial and determines where the signal deviates more than a threshold, which may be determined from the average noise. Our results indicate that this would be possible for the target lines used in our test using by accumulating the signal in a relevant part of the spectrum. To enhance the signal-to-noise ratio one could analyze the overall spectrum with a singular value decomposition. Our results indicate that for this particular target, with a clear spectral color, the enhancement could be present but is not likely to be very strong. The peaks appear somewhat larger but so does the noise. In cases where the spectrum is more subtle, better results may be obtained. Test with various targets and conditions will be necessary to get a better understanding.

Before we can obtain more useful images a number of practical issues need to be resolved. The alignment requires attention for this type of line imager as well as focusing of the image and spectral part of the detector. A particular issue that needs to be solved before outdoor application is possible is the

light intensity e.g. by means of a diaphragm in front of the imaging lens. We are presently developing calibration targets for spatial and spectral focusing and alignment with the camera. This will help to further improve spectroscopy and resolution.

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