Status of the Norwegian hyperspectral technology demonstrator

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ABSTRACT

The Norwegian defence research establishment (FFI) is building a technology demonstrator for hyperspectral target detection. The demonstrator system will integrate hyperspectral and conventional imagers with on-board real-time processing for target detection. The system is built around a hyperspectral camera working mainly in the visible and near-infrared (VNIR) spectral range. Image data will be processed using statistical algorithms, in part developed at FFI. Time-critical parts of the algorithms are executed in parallel on a graphics processor. An important objective of the project is to establish an easily accessible way of performing airborne hyperspectral trials for purposes ranging from scientific studies to operational experimentation and exercises. The first flight of the system is planned for spring 2008 in a single-engine aircraft. A ground-to-ground demonstrator system has also been developed and is currently being used in trials. The paper gives an overview of both the airborne and the ground-based demonstrator systems and discusses the processing speed gain obtained through the use of a graphics processor.

1.0 INTRODUCTION

1.1 Hyperspectral imaging

Hyperspectral imaging has potential to provide improved situation awareness in a variety of military applications. By collecting and analyzing spectral information, a hyperspectral system can perform several fundamentally different types of tasks including

- selective recognition of particular materials (or gases) according to a specified spectral signature
- detection of "foreign" or "rare" materials in a large background (anomaly detection)
- detection of localized changes in a scene between hyperspectral recordings at different times.

Unlike many other sensors, output data from a hyperspectral sensor cannot be directly visualized for an operator. On the other hand, the rich amount of data in each pixel of the image facilitates computer processing, so that an important aspect of hyperspectral systems is the potential for improved automation of detection tasks.

In terms of military applications, hyperspectral imaging is known to have significant potential for target detection, counter-camouflage, airborne surveillance and detection of mines and IEDs. As for other optical sensors, a variety of platforms and concepts of operation are possible, ranging from vehicle-mounted sensors to satellites. Figure 1 illustrates hyperspectral target detection from an airborne platform, possibly the most interesting concept for military applications.

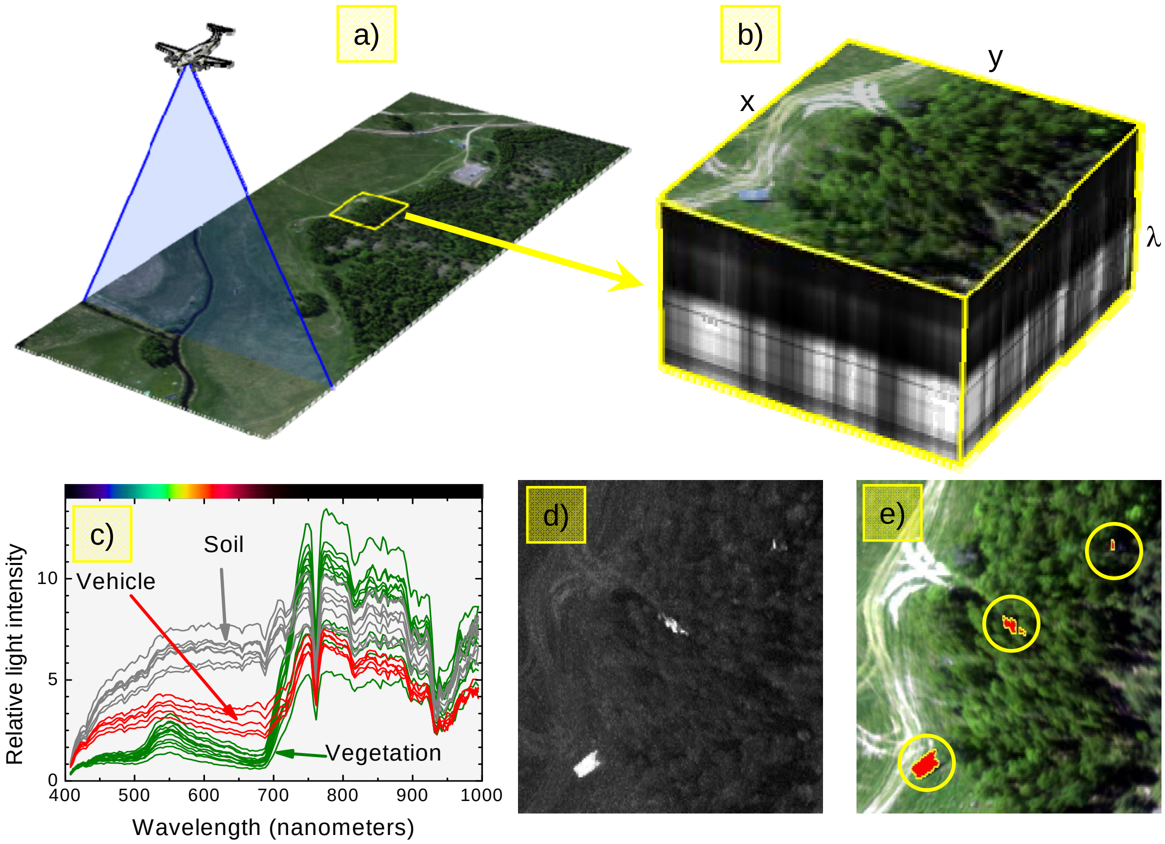

Figure 1. Airborne hyperspectral target detection concept illustrated with data from the HySpex camera to be used in the demonstrator. a) An airborne camera records hyperspectral imagery in a pushbroom scanning mode. b) A section of the imagery illustrates that the data is a "cube" which can be considered a stack of images recorded in different spectral bands. This particular section contains three vehicles of which only one is readily visible. c) The graphs show spectra extracted from individual pixels in the image, illustrating that different materials exhibit different spectral signatures. d) Intermediate result from spectral anomaly detection showing lighter shades for pixels with lower probability of belonging to the background. e) On an operator display, targets can be highlighted in an RGB image of the scene. A high spatial resolution camera provides additional imagery (not shown) to assist operator interpretation of the result.

Despite its obvious potential, hyperspectral technology is still far from being fully exploited. This is in part a chicken-and-egg problem: It is difficult to generate demand from users and develop concepts of operations without fieldable systems, which in turn will not be developed and deployed unless there is a demand for them. Here technology demonstrators play a key role by bringing potential users in direct contact with actual systems which integrate hyperspectral imaging with image processing in real time.

FFI, the Norwegian defence research establishment, has been studying hyperspectral imaging since 2001, including participation in European research collaborations[1]. In order to explore the many possible applications, FFI is now building a demonstrator system which incorporates a hyperspectral sensor, data processing and visualization in a fieldable system. An important rationale for making an in-house development of a fully functional system is to maintain insight into all parts of the system in order to be able to interpret results and make modifications and upgrades to the system. The system will be used in national and international field trials as well as for more scientific and technical studies. Two different versions of the system are being made, one ground-based and one airborne. The ground based version is already operational. Originally scheduled to finish at the end of 2008, the development of the airborne system is now expected to slip into the first part of 2009, but a preliminary version will be flown in the summer of 2008. Flight services are provided by the Norwegian voluntary flying corps with a view towards using the system for search and rescue purposes and similar applications.

Numerous systems integrating hyperspectral imaging and real-time processing have been built in the past, including WAR HORSE[2] and ARCHER[3] in the US. Judging from the open literature, there is a significant gap in the exploration of such integrated systems from the US to Europe. In this context, FFI's demonstrator system is on one hand a late arrival, but on the other hand a significant step forward in Europe. As a new system, it benefits from making use of the latest in computing hardware, where parallel processing is about to become mainstream, enabling ever more complex processing in real time.

This paper gives the status and outlook for the demonstrator development, and gives a discussion of some central technical aspects of the system. In particular, the paper discusses the use of graphics processors for parallel processing of large data volumes.

2.0 SENSORS AND PLATFORMS

The system is based on the HySpex line of hyperspectral cameras[4] manufactured by Norsk Elektro Optikk AS (NEO). These are pushbroom line scanning cameras for airborne use as illustrated in Figure 1. The demonstrator will primarily use a HySpex VNIR-1600 hyperspectral camera covering the visible and near-infrared wavelength range from 0.4 to 1 µm. This camera is characterized by a very high spatial resolution, 1600 pixels over a 17-degree field of view across the flight track. Thus the instantaneous field of view (IFOV) of a pixel in the across-track direction is 0.19 mrad, while the along-track IFOV is 0.36 mrad as defined by the camera slit. In its standard configuration, the camera records 160 spectral bands with a spectral sampling interval of 3.7 nm. In the demonstrator, groups of 4 bands will be combined, resulting in 40-band data. The camera is capable of running at line rates up to about 160 lines per second.

An additional HySpex module may optionally be used to record data in the shortwave infrared (SWIR) wavelength range from 1 to 2.4 µm. This module employs a mercury cadmium telluride detector and has a more modest spatial resolution of 320 pixels over a 14-degree field of view. In the first stages of system development, it is foreseen that the SWIR module will only be used for data collection and not for real-time processing because of the difference in spatial resolution between VNIR and SWIR.

In addition to the hyperspectral cameras, the system employs a Dalsa Piranha2 line scan camera with 8192 pixels. The line scanner has its field of view aligned with the hyperspectral camera and records a monochromatic image of the same scene with high spatial resolution. Nominally, one VNIR hyperspectral pixel area corresponds to 50 line scanner pixels. This enables the system to produce high-resolution images of detected objects for manual inspection by an operator.

Besides the cameras, the airborne system will also incorporate a GPS receiver and an inertial measurement unit for navigation. The raw navigation data are post-processed by Kalman filtering using well established software developed at FFI, resulting in position and attitude data suitable for georeferencing of the images.

To get the system airborne, FFI collaborates with the Norwegian voluntary flying corps who provide flight services to government agencies based on the resources of civilian flying clubs. The hyperspectral demonstrator system will be flown in a Cessna 172 single engine 4-seat aircraft which has been modified with a camera hatch in the floor to accommodate the demonstrator system. The aircraft is conveniently stationed at an airfield just across the street from FFI, and it is envisaged that it can be operated in a reasonably flexible manner for development, testing and use of the demonstrator system.

An additional sensor package has been built for ground-based hyperspectral demonstrations. This sensor package contains a HySpex VNIR hyperspectral camera, a line scanner monochrome camera and a motorized turntable mounted on a tripod. The rotation axis and the linear field of view are vertical so that the cameras scan around the horizon. The instrument is controlled by a PC which also processes the image data. Figure 2 shows the ground-based system on a field trial.

Figure 2. A ground-based camera setup has been built for operational testing in ground-to-ground scenarios. The picture on the left shows an early trial of the ground based system in northern Norway. On the right is the Cessna 172 which has now been modified to accommodate the airborne demonstrator system. The inset shows the HySpex VNIR hyperspectral camera to be fitted in the aircraft together with a real-time processing system and supplemental sensors.

3.0 PROCESSING SYSTEM

FFI's demonstrator system employs statistical methods for the image processing. For spectral anomaly detection, the basic algorithm is based on estimation of a Gaussian mixture model to represent the background spectral distribution. The algorithm is based on well-known statistical methods and is outlined in Ref. [5]. For signature-specific target detection, the basic algorithm is a physics-based statistical signature model (PSSM) for the target spectral properties[6] inspired by the invariant subspace method of Healey and Slater[7]. The PSSM is able to take into account uncertainties in the measurement conditions such as cloud cover and shadowing while accommodating physical knowledge about the measurement situation to the extent that it is available. In addition to the basic statistical algorithms, the system will employ methods for post-detection filtering to reduce false alarm rates.

The hyperspectral sensor and line scan camera produce large volumes of data. Before any data reduction, the data rate is several tens of megabytes per second. The data volume has traditionally been considered a main challenge in processing of hyperspectral data. However, in the last few years the performance of commodity computer hardware has become more compatible with hyperspectral data rates. High-speed interconnects, solid state disks and parallel processing architectures all contribute to making hyperspectral processing a less daunting task than it used to be.

An interesting aspect of the processing part of FFI's demonstrator system is the use of a graphics processing unit (GPU) for parallel processing of the data. It has long been known that the graphics cards used for computer games and other high performance visualization have significant processing power, particularly for parallelizable computing tasks. To exploit this power, it has until recently been necessary to reformulate the task into a form recognizable by a dedicated GPU with graphics-specific functionality. Recently, however, major manufacturers have announced GPU products with architectures capable of general purpose computing, notably the CUDA system from Nvidia[8]. These new products make it significantly easier to tap the power of GPUs using conventional programming languages. At the same time there is a trend for mainstream computing to move towards multiple processing cores. However, in terms of peak FLOPS and data throughput commodity, GPUs have significantly higher performance than even high-end desktop computers. It is now possible to write optimized GPU programs to handle a wide range of tasks characterized by parallelizability and high intensity of arithmetic operations. Many, if not most, types of hyperspectral image processing fulfil these criteria and are well suited for GPU processing.

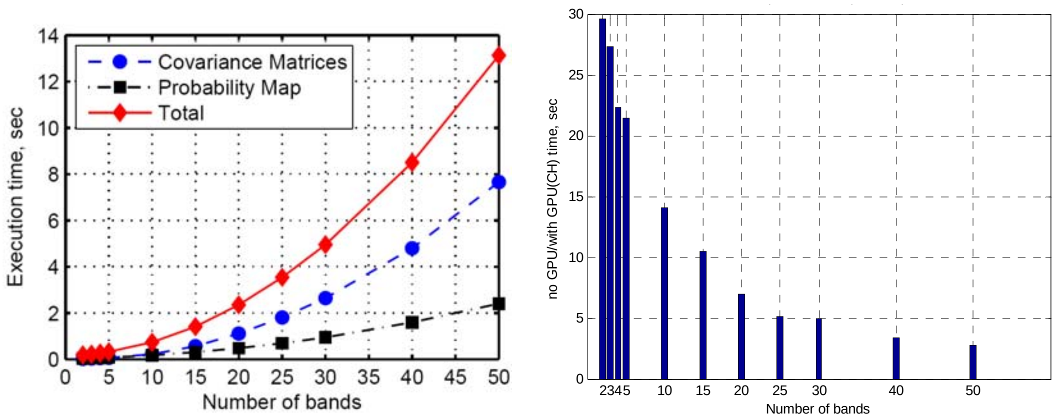

Figure 3. The graph on the left shows the execution time on a GPU for a test task representative of spectral anomaly detection using Gaussian mixture models, as outlined in the text. The task takes as input a HySpex image with 1200 lines corresponding to 2 megapixels or about 10 seconds of data. The number of spectral bands is varied, and the effect on execution time is shown. The results suggest that the GPU is capable of real-time processing of data up to about 40 bands. The diagram on the right shows the performance gain of the GPU relative to an equally optimized code running on an 8-core high-end PC. Depending on the number of bands, substantial speedups of a factor 10 or more can be obtained.

For FFI's hyperspectral demonstrator system, an Nvidia GPU will be used for several processing tasks. Figure 3 illustrates the gain in processing speed compared with a high-end 8-core desktop computer. The figure shows the execution time for a representative test task, executed on an Nvidia GeForce 8800 Ultra GPU. The test task consists of a fixed number of iterations of a maximum likelihood based fitting algorithm for a multivariate Gaussian mixture model for a hyperspectral background distribution. The task also includes calculation of probability density values for each pixel. The test task represents the most computationally intensive parts of the spectral anomaly detection algorithm. The figure shows GPU execution time and speed gain relative to a conventional multicore processor for varying number of spectral bands. The code for both the two different implementations has been carefully optimized. Figure 3 shows that the GPU execution time increases approximately proportional to the square of the number of bands. This superlinear increase is related to the calculation of covariance matrices, a task which is not ideally adapted to the GPU architecture. Nevertheless, we see that the gain in processing speed over a high-end multicore processor is substantial even for data with several tens of bands.

In the demonstrator system, the number of bands will be reduced by combining the original bands into fewer bands of unequal width. The band configuration will be software configurable to allow some adaptation to different tasks. For example a band selection algorithm such as that in Ref. [9], may be used to optimize anomaly detection performance over a wide range of scenes. Such optimization tends to suggest that band combinations with less than 10 bands may be permissible, but the number of bands will be kept somewhat higher than the suggested minimum in an attempt to avoid overtraining effects. From Figure 3, we see that real-time processing is possible with a complex algorithm even at the 40-band resolution, so that lower spectral resolutions will give a significant margin on processing speed.

The user interface part the system will have a functionality similar to that of the ARCHER system[3].

Processing results will be presented for an operator in the airplane. One screen will display a georectified image of the entire area surveyed, to provide an overview and monitor coverage on the ground. Another screen will display image sections around detected objects. The visualization functionality is still under development at the time of writing.

5.0 SUMMARY AND CONCLUSIONS

This paper has presented FFI's work towards a demonstrator system for hyperspectral target detection. A ground-based system has been completed and development of an airborne system is ongoing. Several critical and difficult parts of the airborne system are already in hand, such as a convenient airborne platform and a capability for data processing in real time. In spite of some delay, the first flight of the airborne system is planned for the summer of 2008, probably with somewhat limited functionality. The work will proceed towards a fully functional system in the summer of 2009.

An interesting aspect of the system is the use of a GPU for processing of hyperspectral data. With new architectures capable of general purpose programming, GPUs are set to become a mainstream technique in many fields in the years to come.

The functionality of the system resembles that of systems developed previously in the US. In Europe, however, the system is a notable step forward for military hyperspectral technology. It is foreseen that the system will be used in national and international field trials, with the aim of bringing hyperspectral imaging closer to operational use.

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