PROJECT DESCRIPTION: Low-light and Fluorescence Hyperspectral Imaging

Project outline

The topic of the project is experimental work in the field of hyperspectral imaging. A brief general description of this field is given below. The applicant, Julio Hernandez, will work mainly at Norsk Elektro Optikk AS (NEO), but in close collaboration with FFI and NTNU.

The main focus of this project is the development of a hyperspectral camera optimized for low-light conditions. Most current hyperspectral imagers, including those manufactured by NEO, are not able to record good data at the low light levels found in fluorescence imaging (of interest in medical applications) or remote sensing at night (of interest in military applications). A low-light hyperspectral camera will be a very useful research tool which can be put to immediate use in ongoing research activities at FFI and NTNU. Further details on the planned research are given below.

The proposed work is expected to yield results which can form the basis of several publications, as discussed below. The main publications will be those describing the design and performance of the low-light camera. When this instrumentation is established, it can readily be used to generate publishable results in the context of applications under study at FFI and NTNU.

Hyperspectral imaging is a fertile and rapidly expanding field of research. This is exemplified by a growing number of employed researchers studying hyperspectral imaging in the three involved organizations: A total of 3 in 2001 will have grown to about 15 by the end of 2008. Furthermore, NEO, FFI and NTNU have a clear interest in collaborating on this topic. In total, this provides an excellent basis for supporting the research proposed in this application.

Organizations involved

Norsk Elektro Optikk AS (NEO) has been involved in design, development and production of hyperspectral imaging systems since the 1995. NEO is marketing a line of hyperspecttral cameras for remote sensing, industry and laboratory applications. NEO has supplied hyperspectral imaging systems and data for scientific use to several Norwegian and international research institutes, including NTNU, UMB, UiB, Fiskeriforskning, Planteforsk, Skogforsk and FFI. NEOs experience in making hyperspectral sensors to industrial quality standards as well as adequate lab facilities provide a good basis for the sensor design to be undertaken in this project, and also provides for a possible commercial use of the results. NEO is broadly engaged in several research collaborations including EU-funded projects and a formalized collaboration with FFI. It is worth noting that NEO is owned by a non-profit foundation which channels company profits back into research.

FFI, the Norwegian defence research establishment, has been studying hyperspectral imaging since 2001, with emphasis on remote sensing and military applications. At present, a focus of FFIs hyperspectral research is the development of an integrated airborne demonstrator system with real-time processing of hyperspectral images, for applications-related experimentation in the field. FFI is also engaged in development of image processing methods, as well as new technology concepts for spectral imaging. FFIs hyperspectral-related research activities are primarily aimed at military applications such as target detection. However, the results may also find use in numerous civilian applications, and FFI is supportive of civilian research and industrialization in this field.

NTNU has several research activities involving hyperspectral imaging. Of interest here is their work towards a number of applications in medicine and biology. At present, NTNU's strength lies in the applications insight and the physics of the measurement processes, while there is a lack of resources for the development of suitable hyperspectral imaging instrumentation.

NTNU is the major education institution for electro-optics in Norway, and hence both FFI and NEO have strategic interests in maintaining and strengthening their links to NTNU.

Hyperspectral imaging

In hyperspectral imaging (or imaging spectroscopy), a specialized camera records images which contain detailed information about the spectrum of the received light. Typically, the light is separated into hundreds of spectral bands which are measured separately, resulting in data representing a densely sampled spectrum at each pixel in the recorded image.

Hyperspectral imaging is currently a very active field of research. In part, this is due to developments in mainstream microelectronics, as it has only recently become feasible to process the large amounts of data recorded in a typical hyperspectral application. The range of applications includes remote sensing (environmental monitoring, land use monitoring, agriculture,defence etc.), industrial inspection/quality control (food, chemicals, pharmaceuticals, paper, waste recycling etc.) and laboratory/scientific/medical uses (diagnostics, forensics, geology, etc.).

Unlike other imaging techniques, hyperspectral images cannot be visualized directly, because the human eye is limited to three primary colours while a hyperspectral camera may record data in hundreds of spectral bands. Therefore, spectral image processing is required as an integral part of a hyperspectral system. Hence the field of hyperspectral imaging is strongly interdisciplinary: Instrument design and operation involves physics, electronics and informatics, while image processing also relies heavily on, mathematics and statistics. Additional fields are brought in by the various applications.

Research opportunities and objectives

It is well known that the amount of light available to a hyperspectral imager is an important parameter in determining the quality of the results. In some applications, however, the available amount of light is fundamentally low. This includes fluorescence imaging as well as low-light remote sensing. In this project, low-light hyperspectral imaging will be a main focus. It is a relatively unexplored field, not least because the task is challenging, but offers potential rewards in the form of interesting applications. It is a main objective of the proposed work to establish instrumentation for low-light hyperspectral imaging.

One important class of applications is medical applications, where hyperspectral imaging in general is a new technique not yet put to full use. Low-light hyperspectral imaging has great potential in combination with fluorescence techniques for the study of tissues. There is a range of possible clinical applications which have not yet been explored, including tissue monitoring and inspection during heart surgery. It is an objective of the proposed work to explore, and hopefully find potential for, such clinical use of low-light hyperspectral imaging.

Another application of low-light imaging is night vision based on reflected (non-thermal) light from originating from the moon, stars and other sources. It is well known that image intensifying equipment can be used for night observation, providing live images of good quality. This suggests that low-light spectral imaging may also be viable at night, at least for recording of still images, but these possibilities remain relatively unexplored. It is an objective of the work to make an initial exploration of night-time hyperspectral imaging using reflected light.

In current hyperspectral research, there tends to be a divide between camera designers, image processing specialists and end users. However, the Hyper-I-Net consortium incorporates all these groups with a goal of arriving at a more unified way of handling hyperspectral image data. One important aspect of the image data is the signal to noise ratio, which is fundamentally limited by photon counting statistics in the camera. In physics, it is well known that photon arrival follows Poisson statistics, but this relation is practically always hidden from data users through preprocessing steps performed on the data. For low-light imaging it is particularly important that the processing makes optimal use of the information present in the data. It is an objective of the work to establish ways of incorporating more detailed information about noise in hyperspectral data, and to promote the use of such information in the image processing community through the Hyper-I-Net collaboration.

Project plan

The following is a somewhat more detailed plan of the research work and the foreseen publications.

The project will begin by a survey of the foreseen applications regarding the expected light levels as well as the requirements for spectral resolution, dynamic range, field of view and other characteristics. The dynamic range requirement may turn out to be a challenge, considering that the medical applications may call for a combination of reflectance and fluorescence imaging, while the military applications may call for day and night operation. Thus an important part of the applications survey is to define requirements for dynamic range and to choose appropriate measurement techniques. The survey results will be documented in the final thesis, and will be used in a compressed form in the planned publications as appropriate.

There exists an interesting possibility to use a fiber bundle to transform a two-dimensional image into a linear form suitable as input to an imaging spectrograph. This may enable "live" hyperspectral imaging with moderate spatial resolution while remaining compatible with medical endoscopy techniques and low-light requirements. Whether to use this technique is an important design choice to be made early on.

A hyperspectral imager will be developed to fit the application requirements, aiming to achieve a performance at or beyond the current state of the art. The imager will be based on an electron-multiplying silicon CCD array or similar technologies to achieve good low-light performance. Thus it is likely that the imager will operate in the visible and near-infrared spectral range from 0.4 to 1 micrometer wavelength. The optical design may take advantage of NEOs current or upcoming camera designs and adapt them to the foreseen low-light applications.

A first journal publication will describe the instrument design and initial results, with examples from tests in medical applications to demonstrate key capabilities.

A crucial part of the design will be to preserve the integrity of the low-light signal and to provide well calibrated data to the user. The data should include information that allows the user to reconstruct estimates of photon statistics and other noise in the data, in order to enable statistically optimal processing of low-light image data. Through the Hyper-I-Net collaboration, methods to represent image noise will be promoted to data users. This part of the work will most likely take the form of a conference presentation and contributions to output reports from Hyper-I-Net.

It is a goal of the project to achieve interaction between applications and instrument design, to promote quality and relevance of the work. Hence initial application experiments will take place as early as practically possible, possibly based partly on existing hardware. Thus an ambition of the project is that the final instrument design should have a foundation in practical experience, to the extent that time permits.

A second journal publication is foreseen to document performance of the final instrument design and demonstrate its capabilities in a relevant medical application.

A main aim of the project will be applications in heart surgery and diagnostics of cardiovascular diseases, where NTNU has established expertise and contacts with medical researchers. Hyperspectral reflectance and fluorescence imaging may aid in inspection and diagnostics of blood vessels. Good animal models exist for these applications, and it is a goal of the project to be able to collect good quality imagery using these models.

The low-light spectral imager to be developed in this project will also provide a capability to test the viability of spectral imaging at night. This is a topic of significant interest for military applications as well as other uses, and the work will incorporate tests of the low-light imager in a relevant night-time scenario.

Depending on the results obtained in application tests, one or two publications will focus more on the implications of low-light hyperspectral imaging in selected applications.