ERCIM "ALAIN BENSOUSSAN"
FELLOWSHIP PROGRAMME

ERCIM
European Research Consortium
for Informatics and Mathematics

Scientific Report

First name / Family name	Joseph Garrett
Nationality	USA
Name of the *Host Organisation*	NTNU (Department of Engineering Cybernetics)
First Name / family name of the *Scientific Coordinator*	Annette Stahl
Period of the fellowship	01/10/2018 to 30/09/2019

I – SCIENTIFIC ACTIVITY DURING YOUR FELLOWSHIP

During my ERCIM fellowship, I worked in the small satellite lab at the Norwegian University of Science and Technology as part of the Robotic Vision group in the Department of Engineering Cybernetics. The lab is currently building an earth observation satellite named HYPSO, the hyperspectral smallsat for ocean observations. HYPSO will be launched in Autumn 2020 and will be part of a larger network of robots that includes *in situ* agents as well as a satellite constellation. My work focused on developing an image processing pipeline for HYPSO including, in particular, designing and testing a method for hyperspectral pushbroom superresolution.

(1) The first parts of the image processing pipeline
The hyperspectral images collected by HYPSO will be pre-processed on-board so that information from many observations can be downlinked, even though the raw data from any one observation is quite large (> 2 GB). The first component of the pipeline must eliminate some artifacts from the detector which cause irregularities in the hyperspectral data, called “smile” and “keystone”. To do this, I first determined the artifacts based on calibrations of the camera performed by a student in the lab. Then, based on some earlier studies, we created a map from the distorted coordinates to a corrected coordinate system. The method worked well, but it was too slow. To enable real-time operation, I re-phrased the map as sparse matrix multiplication so that we could utilize the speed of (parallelized) linear algebra. We achieved correction rates of about 10 ms per frame on a desktop

computer. The student will be presenting these results at the WHISPERS 2019 conference in Amsterdam. Another student in the lab is now working on developing a similar procedure on an FPGA to enable remote agents to quickly run the corrections.

After each individual frame of the hyperspectral image is corrected, it is necessary to locate the relative positions of the frames in order to create an image, which is a process called image rectification or registration, if the coordinate grid is pre-determined (for example, in relation to another image). Because image registration is critical to superresolution, I was closely involved with the design of the image registration procedure and helped a student in the lab to implement a Python version of it. Our design combines navigational data (position, orientation) with knowledge about the geometry of the scene and about the point-spread function of the camera to project each measurement onto the scene. One output of the registration method is a matrix describing the relationship between the measurements and the registered image. This matrix is critical to the superresolultion techniques that were developed in the next step.

(2) Superresolution

Superresolution is the process of combining multiple low-resolution observations, typically also with some external information, to produce a higher-resolution image. Developing a superresolution technique for hyperspectral imagers would open up a wide range of applications for them, because design considerations usually restrict their resolution relative to equivalent red-green-blue (RGB) cameras. Much progress has been made towards integrating a hyperspectral camera together with a higher-resolution RGB camera, but the hyperspectral superresolution (HSR) scenario without the higher-resolution camera has only been minimally explored.

Most previous superresolution algorithms have been developed for monochrome images. I started my exploration of HSR by adapting two monochrome superresolution algorithms to the hyperspectral case: projection onto convex sets (POCS) and robust superresolution (RSR). At the start of my fellowship, I was a little skeptical that HSR could actually improve image quality. Thus, my first tests of the two algorithms looked at how they each affected the spectral angle (color quality) and brightness accuracy when reconstructing simulated images. I found that both algorithms lead to some improvements, but that the improvements from RSR were greater. I presented these results at the OCEANS 2019 conference in Marseille, France. Although POCS allows more flexibility, the better results and relative simplicity of RSR caused me to focus on developing and testing it more during the rest of my fellowship. However, I still think that the flexibility of POCS implies that it could be developed for interesting niche applications. With Prof. Stahl, I came up with a new test to inspect which spatial frequencies of an image are enhanced by superresolution and to see if there is any anisotropy to the enhancement.

II – PUBLICATION(S) DURING YOUR FELLOWSHIP

J L Garrett, S Bakken, M Grøtte, D Lager, E F Prentice, T A Johansen, A Stahl, "Robust superresolution for push-broom hyperspectral imagers" *manuscript in preparation*

M B Henriksen, J L Garrett, E F Prentice, F Sigernes, A Stahl, T A Johansen, “Real-time Corrections For A Low-cost Hyperspectral Instrument” *WHISPERS 2019 proceedings*

J L Garrett, D Langer, K Avagian, A Stahl, “Accuracy of superresolution for hyperspectral ocean observation” *OCEANS 2019 proceedings*

III – ATTENDED SEMINARS, WORKHOPS, CONFERENCES

1. OCEANS 2019, Marsielle, France 17.06.2019-20.06.2019
2. VISUM 2019, Porto, Portugal 04.07.2019-12.07.2019

IV – RESEARCH EXCHANGE PROGRAMME (REP)

Laboratório de Sistemas e Tecnologia Subaquática, FEUP, Porto, Portugal

Duraction: 24.06.2019 – 28.06.2019
Contact: João Sousa
Website: https://lsts.fe.up.pt/

About: LSTS is a interdisciplinary laboratory that speacializes in “the design, construction, and operation of unmanned underwater, surface and air vehicles and the development of tools and technologies for the deployment of networked vehicle systems”. Moreover, they have developed and maintained the DUNE Unified Navigational Environment (DUNE) which is a lightweight open-source software for operating ensembles of autonomous vehicles.

Experience: I visited LSTS while they were on a mission to map the seafloor of a nearby protected shoreline with sonar to aid in conservation of marine habitats. While I was there, I spoke with the group about the HYPSO project at NTNU and my work on the project, and discussed possibilities for future collaborations, particularly when choosing the *in situ* robotic agents that will operate together with the satellite. Because of the ongoing mission, the researchers were able to show me how the robots worked in the field. The atonomous underwater vehicles (AUVs) switched between several different communication channels depending on whether or not they were underwater and whether or not they were within the range of the science-vessel’s wifi. I was particularly intrigued by this clever use of redundency and am looking into ways to incorporate it into HYPSO.

Note that this visit is an exceptionally agreed INESC visit. I misunderstood the membership of the different constituent organizations of INESC and thought that FEUP is more closely associated with INESC than it actually is. However, INESC was kind enough to forgive this misunderstanding and allow this REP to count towards my ERCIM requirements. For that, I am very grateful.