Sampled Imaging Systems

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The past few years have seen the development of an extensive array of InSb and PtSi midwave focal plane arrays and this trend continues with HgCdTe, quantum wells, and thermal detectors. These focal planes provide for less complicated systems, and the longer detector integration time improves the overall system sensitivity. However, a common characteristic of imagers that use these focal planes, unlike first generation thermal imagers, is that they are often undersampled.

The field performance of undersampled imagers is not well understood. The field performance of first generation imagers can be predicted based on standard laboratory measurements like minimum resolvable temperature difference (MRTD) and minimum resolvable contrast (MRC). For sampled imagers, the relationship between field performance and MRTD has been lost. A major modeling thrust at the U.S. Army Night Vision and Electronic Sensors Directorate is to update current sensor performance models to include the effects of undersampling. A number of researchers are attempting to define the meaningful laboratory measures for sampled imagers and to relate the laboratory measures to field performance.

The end to the cold war and resulting reduction in military budgets has led to an increased emphasis on simulation and modeling. It is hoped that both time and money can be saved by developing sensor systems in a ‘‘virtual world.’’ However, simulation-based acquisition requires a degree of realism and fidelity that our simulators and models currently lack. Sampling issues affect sensor simulation in two ways. First, the real-world scene and sensor optics are continuous but computer-generated imagery and processing are sampled. The sampled-sampled-continuous process implemented with a digital simulator must accurately depict the continuous-sampled-continuous process of a real sensor system. Second, some of the sensors to be simulated are undersampled; the digital simulator must be capable of generating imagery with realistic sampling artifacts. It is important to understand these issues and design simulations with acceptable error bounds.

We are pleased to take part in this special section of *Optical Engineering* on sampled imaging systems. The collection of papers included in this section covers a broad range of topics that are important in the characterization and simulation of sampled imaging systems. This section begins with five papers on the performance modeling of static imagers (the scene is not moving across the sensor field of view). Huck et al. take an information theory approach to sampling where communication theory guides the sensor design for optimal image collection, transmission, and display. Vollmerhausen, Driggers, and O’Kane then provide a performance model based on imager spurious response for the tasks of recognition and identification. Wittenstein provides an additional performance model concept that is similar to the MRTD, but with the addition of sampling effects. Hadar and Boreman evaluate sampled imaging systems with an image fidelity measure of bandwidth. Finally, Park and Rahman provide an end-to-end analysis of a continuous input, discrete processing, and continuous output imaging system in order to characterize spurious responses in the imagery as fixed-pattern noise.

The properties of sampled imaging systems change whenever the image or the sensor is placed in motion relative to the other. The motion can degrade the image with an increased blur: the detector collects light over a finite time and the motion causes the image to smear. However, the motion can also increase the spatial sample rate of the scene if multiple images are combined. There are two papers in this section on combining data from multiple time sequential images to improve the spatial sample rate of the scene. The first paper, by Schuler and

Scribner, describes a technique using optical flow calculations to combine image sequences to achieve super sampling of a scene. The second paper, by Tuinstra and Hardie, describes a technique for application to objects which can be segmented within the scene; again, data from multiple images are combined to provide improved resolution of the segmented object.

The intelligence, surveillance, reconnaissance (ISR) community evaluates imagers differently than the tactical community. The National Imagery Interpretability Rating Scale (NIIRS) is used to describe the performance of ISR remote sensing systems. There are two papers in this special section addressing the NIIRS modeling of these sensors. The first paper (Fiete and Tantalo) characterizes the performance increase due to an increase in the along-scan sample rate. The second paper (Smith et al.) describes the degradation in the NIIRS performance as a function of image smear.

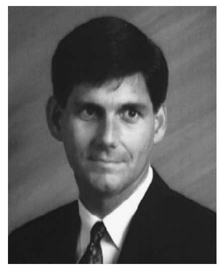
The simulation of sampled imaging systems is comprised of a completely different set of problems. In most cases, we emulate a continuous-sampled-continuous system with a sampled-sampled-continuous system. This difference in process is usually accompanied by errors and must be considered carefully to provide an accurate rendition of the imaging system. Two papers in this special section are related to the simulation of sampled imaging systems. The first paper describes the errors associated with the simulation of imaging system transfer functions (Jacobs and Edwards). The second paper describes the development of operational performance metrics using image comparison calculations. These metrics and calculations are applied to sampled imagery with a concept of degradation space (Halford et al.).

Establishing repeatable, meaningful laboratory measurements for sampled imagers is just as important as the modeling of field performance. Two papers are included that describe the performance measurement of sampled imaging systems. The first paper (Webb and Halford) describes a dynamic method of measuring minimum resolvable temperature (MRT) that minimizes the problems of phasing and sampling in the static MRT measurement. The second paper (Driggers et al.) is a tutorial on the performance measurement of sampled imaging systems. This paper presents a discussion of the problems that are yet to be addressed but must be addressed prior to accurate performance predictions of these systems.

There are two papers included in this special section that describe signal-to-noise-related phenomena for staring imagers. First, Gross, Hierl, and Schulz describe the long-term stability of non-uniformity correction in infrared focal plane arrays. In the second paper, Prather describes a method for increasing the fill factor with monolithic integration, sub-wavelength lenses. A design algorithm is described that uses the boundary element method of diffraction modeling. Examples of a microbolometer and a quantum well detector are provided.

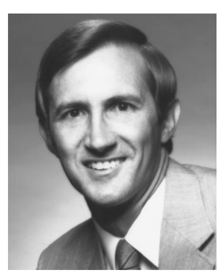
The final three papers provide an interesting cross section of sampling issues. Chen, Karim, and Hayat describe an approach for eliminating higher order aliasing by using multiple interlaced sampling. In the next paper, the same authors investigate band-pass sampling effects from joint transform correlations. Then, Khriji, Alaya Cheikh, and Gabbouj provide a paper on digital re-sampling using vector rational filters.

We are pleased with the manuscripts submitted and the interest in sampled imaging systems. We are also honored to be among the group of sampled imaging system researchers that made this special section of *Optical Engineering* possible. This is certainly an important topic that will become more important as focal plane array infrared systems are fielded. We hope that you enjoy these papers and that they are useful in your studies of sampled imaging systems.



Ronald G. Driggers graduated from the University of Memphis with the PhD degree in electrical engineering in 1990. He performed his dissertation at the University of Central Florida's Center for Research in Electro-Optics and Lasers. He has specialized in infrared and electro-optical systems with an emphasis on performance modeling, reticle modulation, multi-aperture systems, and radiometry. He has 12 years of electro-optics experience and has worked for or consulted to Lockheed Martin, Science Applications International Corporation, EOIR Measurements, Amtec Corporation, Joint Precision Strike Demonstration Project Office, and Redstone Technical Test Center. He is currently working for the U.S. Army's Night Vision and Electronic Sensors Directorate. Dr. Driggers is the U.S. representative to the NATO panel on advanced thermal imager characterization and is an associate editor of *Optical Engineering*.

Richard Vollmerhausen received a BS and MS in physics from Arizona State University. He currently heads the Theoretical Modeling Branch at the Army's Night Vision Lab. The branch is updating the Army's target acquisition models to include the effect of sampling on performance and to make other model enhancements in order to predict the performance of advanced technology sensors. During this tenure at NVL, he has been a project engineer and EO systems analyst for numerous Army weapon systems. His previous work included designing air-to-air missile seekers for the Navy and working as an instrumentation engineer for Douglas Aircraft on the Saturn/Apollo Program.



Carl E. Halford is a professor in the Department of Electrical Engineering at the University of Memphis. He received the PhD degree from the University of Arkansas, Fayetteville, in electrical engineering. His research interests include infrared sensors, infrared scene projectors, multi-aperture sensors, and uncertainty analyses associated with electro-optical testing. In addition to electro-optics, his teaching interests include signal processing and a wide variety of undergraduate subjects. His summer/consulting experience includes work with the Army's Test and Evaluation Command at Redstone Technical Test Center, Lockheed Martin in Orlando, the Army's Missile Command at Redstone Arsenal, and NASA's Johnson Space Center. Dr. Halford has more than 40 publications in electro-optics.