2. PUBLISHABLE SUMMARY

The main objective of the research effort in the project "Compressive data acquisition and processing techniques for sensing applications" (COMPSENSE) is to develop and integrate compressive sensing principles for a range of signal processing and data sensing problems. The research is comprised of three main sub-thrusts: 1) Compressive remote sensing 2) Multi-sensor and distributed compressive sensing 3) Detection and estimation methods based on directly on compressive data. In addition to these research objectives mobility and integration objectives are to promote the reintegration of the researcher to his country and host institution, and to establish collaborations with local and European researches. In order to fulfill these objectives, a vast amount of work has been carried out, and the main results achieved so far are summarized below:

The compressive remote sensing objective was aimed at developing novel, fast and robust data acquisition and imaging techniques for initially ground penetrating radar (GPR) and extending these results to other remote sensing sensor types. To achieve this objective first the computation load of optimization in CS for remote sensing problems are analyzed. Two approaches for faster reconstructions are proposed. In the first approach, greedy sparse reconstruction techniques are analyzed and it has been shown that orthogonal matching pursuit (OMP) based imaging method could achieve a similar performance compared to solving basis pursuit optimization problems with much smaller computation times. In the second approach, the computational and memory requirements for 3D subsurface imaging problems are decreased by using symmetry properties of GPR data acquisition process resulting dimension reduction in the sparsity dictionaries.

One of the problems in this CS subsurface imaging is the surface reflections. The existing literature was discarding ground reflections and the standard ground reflections removed algorithms were inefficient for the random compressive measurements. The proposed technique provides a simple surface reflection method using compressive measurements, that can be used for nonplanar surfaces. It is observed in both simulated and experimental GPR data that the CS-based imaging method is more robust and can find shallow targets using the surface-reflection-removed data.

Initial results obtained in subsurface imaging are extended to through the wall imaging (TWI) results. In these works, performance of the proposed imaging is outlined under the questions on the required number of measurements for a sparsity level, measurement strategy to subsample in frequency and space, or imaging performance in varying noise levels and limits on CS range resolution performance are answered. In addition current CS-based imaging methods are based on two basic assumptions; targets are point like and positioned at only discrete grid locations and wall thickness and its dielectric constant are perfectly known. However, these assumptions are not usually valid in most TWI applications. The effect of unknown parameters on the imaging performance is analyzed, and it is observed that off-the-grid point targets and big modeling errors decrease the performance of CS imaging.

The performance degradation where basis mismatch occurs is a general problem in all CS reconstruction problems. For robust reconstruction of signals under basis mismatch problem two new algorithms are proposed and shown to be very effective in several reconstruction problems such as GPR imaging, delay Doppler imaging, frequency estimation, and SAR imaging. If the dictionary is created through a discretization of a continuous parameter space, then the proposed technique perform perturbations on the parameters by applying an iterative OMP method that uses gradient based steepest ascent-type iterations to locate the off-grid target. Under a general random basis perturbation case, the proposed perturbed OMP (POMP) algorithm applies controlled perturbation mechanism on the selected dictionary columns. The selected column vectors are perturbed in directions that decrease the orthogonal residual at each iteration. Proven limits on perturbations are obtained. The proposed method is fast, simple to implement and successful in recovering sparse signals under random basis perturbations.

The CS based imaging knowledge in GPR and TWI areas are also extended to other remote sensing problems. In this context, first the location information of targets for electromagnetic induction (EMI) sensor are extracted using a model based dictionary with an OMP based algorithm. The obtained results from experimental EMI data has shown that different types of metallic targets are correctly located where current techniques cannot generate any depth information from EMI data. Secondly, CS is applied to synthetic aperture radar (SAR) imaging problem. A new solution for the autofocus problem in SAR is proposed by using the developed expectation maximization based matching pursuit algorithm in this project. Robust delay-doppler scene imaging is another extension of CS based remote sensing applications.

For the objective of multi-sensor and distributed compressive sensing first, a new technique for direction of arrival estimation based on compressed measurements is developed and analyzed in detail for estimation bias and variance for varying noise level, resolution limits, multitarget and underdetermined system cases. This DOA estimation algorithm is combined with sparsity information on the target signals to achieve sparse blind source separation signals. Second research topic focuses on characterization of savings in communication energy and network lifetime comparing the communication loads of compressive sensing and standard communication techniques. Energy dissipation models for both CS and conventional approaches are built and used to construct a Mixed Integer Programming (MIP) framework that jointly captures the energy costs for computation and communication for both CS and conventional approaches. Numerical analysis is performed by systematically sampling the parameter space (*i.e.*, sparsity levels, network radius, and number of nodes). Our results show that CS prolongs network lifetime for sparse signals and is more advantageous for WSNs with a smaller coverage area. A new iterative sparse reconstruction technique that is also suitable for multi sensor applications is developed that is based on expectation maximization.

For the objective of detection and estimation method based directly on CS measurements, the goal was to develop methods that use CS measurements but could extract features or generate detection or estimation results without first reconstructing the signal itself. In this context, first parameterized features such as lines in images are sparsely reconstructed observing that these features are sparsely represented in the generalized Hough transform domain. The results indicate enhanced shape detection performance, increased resolution, joint detection of different shapes in an image and robustness to noise. In another work the two stages of image formation and feature extraction is combined within the CS framework and the feature parameters directly from the raw sensor measurements without having to construct an image of the sensed media. In addition to skipping the image formation step, CS processing can be done with a minimal number of raw sensor measurements, which decreases the data acquisition cost. Sparse delay-doppler detection of targets and selection of CFAR thresholds in sparse delay doppler scenes for CS based algorithms are also studied.

Regarding the fulfillment of integration objectives, the researcher attended 6 international conferences and 5 local conferences in Turkey. The research work within the project resulted 6 published journal papers, 7 international and 10 local conference proceeding papers and 3 masters thesis. He was also an invited to give speeches in local workshops and seminars on compressive sensing. These activities resulted in fruitful collaborations from local and European researchers. The detailed information about the project is given in project website: http://www.acgurbuz.etu.edu.tr/compsense.htm