Interior Intelligence by Networked Sensing, Imaging and Global Hierarchical Tomography (I2NSIGHT)

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Remote estimation of complex internal building structure is an extremely challenging inverse problem. Microwaves in various frequency ranges are capable of building penetration, but the resulting observations are sensitive to a host of influences, including layout geometry, interior and exterior wall thicknesses and EM properties (dielectric constant, conductivity), existence of doors and windows, and clutter objects within the building. Further, collected data sets will display significant variability depending on source-receiver geometry, as well as antenna design and bandwidth of the probing radiation. The complexity and variability of the resulting inverse problem requires innovations in sensor architecture (adaptivity and cooperation), fusion and estimation (closed-loop model estimation over the vast parameter space alluded to above), sensor design and deployment (sensor mode and form factor, geolocation, optimal CONOPS) and implementation (robustness, fast and practical computing).

Our approach exploits our detailed understanding of the physics of microwave propagation to build a model-based, maximum-likelihood framework. It integrates numerous measurement types, and provides criteria for adjustment of sensor collection parameters, for closed-loop estimation of internal structures and people. Successful strategies will require a combination of approaches to constrain the model parameter space, yet must be robust and practical enough for tactical deployment. Our hierarchical model estimation approach achieves accurate and efficient solutions by integrating ray racing tomography, to deconvolve multiple paths for imaging detailed structure through a few walls, with diffusion tomography, to image mesoscale features of large and complex building deeper interiors by actually exploiting multipath effects. This process iterates as new data is acquired, and is additionally constrained by our imaging approaches. Our system design incorporates highly flexible sensors and wireless networking for easily deployable, unconstrained configurations that scale to improve model estimation performance with increased number of sensors.

Project risk is greatly reduced by planned data collections from the outset which will support algorithm development and performance verification in continuous spiral development cycles through all phases. A channel sounder will be used for extensive and continuing real-building data collections on the Bell campus. This activity, which will greatly augment the government field collections, will start from nearly the beginning of Phase I, and will be critical for effective algorithm development. These collections will be strongly complemented by phenomenological data to be collected by Villanova University (VU). In addition, the Colorado School of Mines (CSM) will collect full-building scale model data with a millimeter wave vector network analyzer, which will allow unprecedented knowledge, control and variation of all model parameters for robust software testing.

Phase I will deliver a validated prototype sensor (based on BAE's distance to fault sensor technology) which will augment the government {requested go/no {go decision inputs and reduce Phase II risk. Our approach strongly leverages Bell Labs' state-of-the-art ray tracing tool WiSE (whose fidelity will be increased even further during the course of the research), extensive previous imaging research performed by VU (which will be significantly generalized here), the diffusion tomography experience of our Tufts and Northeastern team members, and the laboratory facilities of the Colorado School of Mines. The project concludes with delivery of eight self-locating sensors and a centralized on-line processor all linked with a wireless network, and poised for rapid transition to the field.