UAB Grand Challenge Concept Paper

Name of the UAB Grand Challenge: Using Building-Envelope Health Maps to Optimize Building Sustenance and Revitalization

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Description of the Problem to be Addressed, including its importance to the State of Alabama and how it is generalizable to other states, the U.S., and the world:

The health and integrity of urban infrastructure is of great concern to our nation, especially in terms of buildings, bridges, roadways, etc. Concerns have been raised regarding public housing in urban areas. For example, in Henrico County, Virginia, HUD performed inspections of public housing giving passing grades in spite of major problems [1]. At an apartment complex, a roof collapsed in the Burton Apartment Complex, but the property received an impressive score of 90 on a recent federal inspection.

One of President Trump's key aims during his time in office is overhauling and revitalizing America's potholed roads, disheveled railways and deteriorating bridges. Illinois and Connecticut have the worst road in the U.S. (73% in each state are in poor or mediocre condition) while according to the government, 70,000 bridges (one out of every nine) are classified as being structurally deficient. According to Forbes Magazine "Crumbling infrastructure will have a knock-on effect on U.S. families' disposable household income. Between 2016 and 2025, each American household will lose $3,400 every year due to infrastructure deficiencies. The severe economic impact mentioned above will also cost some 2.5 million jobs by 2025, according to the report. Without investment, that number should reach 5.8 million by 2040." [2]

The American Society of Civil Engineers (ASCE) indicates deteriorating urban infrastructure has resulted in 5 adverse effects [3]: reducing disposable income; generating fewer jobs; costing hours stuck in traffic, increasing prices for goods, and creating a domino effect on all aspects of life.

The overarching goal of the proposed UAB Grand Challenge is to regenerate sustainability in the existing building stock by infusing building sustenance and revitalization in sustainability-related components, such as energy efficiency, environmental durability, and structural performance. Our objective is to evaluate and analyze the existing health of the building-envelope and to recommend a viable remediation/retrofit guideline.

We propose real-time building evaluation and health analysis using multi-modal technology comprised of fly-by drones equipped with lightweight magnetic coils to generate surface-penetrating field waves. Reflected impedance values and geometric patterns of scanned buildings will be analyzed for physical dimensional changes and "heat map" changes for diagnosing a building's health condition as a function of its: structural environment (e.g., a combination of seismic, wind, and blast threats), energy efficiency (e.g., *R*-value and thermal conductivity), and environmental health (e.g., changes in the valance of metal species, such as pipes, indicating potential corrosion). The proposed "fly-by coil" architecture may ascertain thermal leakage in buildings via reduced *R*-value in identified walls and ceiling regions; sinkhole formation or foundation cracks due to settlement; reduction in impact-resistance or lateral load resistance in walls following a tornado or seismic event; damage to underlying roof deck or curled roof tiles following a hurricane event; and environmental contamination: (a) indoor air pollution caused by mold, mildew, and building adhesives or (b) outdoor air pollution caused by ceiling-wall cracks leading to an increase in the number of daily air exchanges.

The proposed research will examine the “building envelope health” analogously to an annual medical exam and diagnosis, followed by an appropriate treatment and prognosis. Analogous to how medical diagnoses vary person-to-person (with a different prognosis and “retrofit plan”), “fly-by-coil” evaluation and analyses will yield customized building sustenance. Simulated wave propagation results of the coil-induced impedance will be used to generate building “health maps.” Indicators of a building envelope’s existing sustenance using health maps will lead to envelope-customization according to a 'retrofit cost-value' model. Depending on the building-envelope prognosis, an appropriate retrofit plan may be prescribed. For example, if "fly-by-coils" detects mold, extensive cracking in a shear wall, and a decrease in wall-insulation density (and subsequent thermal loss and increase in the number of daily air exchanges, AE), one remediation solution may be to patch the infected region with a 'patch-polymer,' whose nano-scale properties may be designed to insulate (R-value), reduce AE, and enhance fracture toughness/ material damping.

Desired Outcomes and the Conceptualization of the Plan of Work to Achieve Them:
Desired outcomes and a preliminary work plan are described below. The project will develop: (1) “fly-by coil” architecture with penetrating field waves to evaluate the health state of the building envelope, (2) multi-physics analysis of building "health-maps," and (3) customized recommendation/guideline to optimize building sustenance, primarily focusing on urban infrastructure and low-income housing. A number of the UAB research have had projects funded along these lines. We believe that our “fly-by coils” concept will garner interest from DoD, DOE, HUD, DHS, and local Community Action Councils (CAC) to improve energy efficiency and structural integrity of urban infrastructure. Research thrusts will include the following thematic areas:

1. Fly-by Evaluation: Due to rapid technological advancements and significant cost reduction, commercial-grade drones are emerging as a technically and economically viable asset that can integrate within a communication infrastructure for coordinated response. Drones can autonomously maneuver and relocate position in both GPS-supported and GPS-denied environments. They may be equipped with advanced communication and computing capabilities that can capture high-resolution images and data using a wide range of on-board sensors and transmit data over ranges up to 2–3 kilometers. The use of a “flock” of interconnected, self-managed drones holds great promise in performing critical risk managing tasks effectively and in real-time. These tasks include real-time monitoring and mapping of inaccessible areas. This research thrust focuses on harnessing potential of a network of swarming drones for structural evaluation and management. We will build on existing coverage and control technology to investigate a hybrid infrastructure of “perched” and airborne “roaming” drones. The perched drones will provide stability and consistency for accurate data collection and processing in a dynamically changing environment. In addition to sensing and data collection from surrounding environments, roaming drones will act as carriers to route and disseminate information efficiently among perched drones, where the collected data is processed. The network of drones will share their processing resources to solve computationally demanding problems quickly. Collectively, deployed drones will automatically form an aerial wireless mesh network, over the scouting area, to process and deliver reliable information for disaster management.
2. Using an easily deployable multi-coil architecture, conducive to field-use, low-frequency magnetic fields will be generated via large coupling strength between transmitter and receiver coils attached to “fly-by” drones to quantify the location and depth of structural and thermal defects in homes, providing cogent “building health maps.” Recorded impedance field-data may be post-processed by simulating radio wave propagations through graphical interpretation, pioneering a prediction-based prognosis using novel scalable retrofit-polymer interfaces.

List of Potential Team Members (individuals and organizations) from inside and outside UAB:

Individuals:

- Dr. Thomas Attard; Associate Professor of Structural Engineering, Department of Civil, Construction, and Environmental Engineering, UAB
- Dr. Mischell Fanucchi; Environmental Health Sciences, School of Public Health, UAB
- Dr. Mohammad Haider; Associate Professor of Electrical Engineering, Department of Electrical and Computer Engineering, UAB
- Dr. Charles Monroe; Assistant Professor of Material Engineering, Department of Material Science and Engineering, UAB
- Dr. Robert W. Peters; Professor of Environmental Engineering, Department of Civil, Construction, and Environmental Engineering, UAB
- Dr. Brian Pillay; Chair, Department of Material Science and Engineering, UAB
- Dr. Hessam Taherian; Assistant Professor of Mechanical Engineering, Department of Mechanical Engineering, UAB
- Mr. Matthew Winslett; Director of Utilities Management, Department of Facilities Management, UAB

Internal Organizations:

- UAB Department of Biology
- UAB Department of Chemistry
- UAB Department of Civil, Construction, and Environmental Engineering (CCEE)
- UAB Department of Electrical and Computer Engineering (ECE)
- UAB Department of Material Science and Engineering (MSE)
- UAB Department of Mechanical Engineering (ME)
- UAB Department of Facilities Management
- UAB Department of Physics
- UAB Innovation Depot
- UAB Office of Sustainability
- UAB School of Medicine
- UAB School of Public Health

External Organizations:

- Jefferson County Department of Health
- Regional Planning Commission of Greater Birmingham – Scott Tillman
- City of Birmingham, Mayor’s Office
- U.S. Department of Housing & Urban Development
- U.S. Department of Defense (DoD)
- U.S. Department of Energy (DOE)
- U.S. Department of Homeland Security

References Cited:

[1] Hipolit, Melissa, 2017. CBS 6 Investigation Funds HUD Passes Section 8 Complexes in Disrepair. [web-link: http://wtvr.com/2017/07/18/cbs-6-investigation-finds-hud-passes-section-8-complexes-in-disrepair/]

[2] McCarthy, Niall, 2017. *Forbes Magazine*. [web-link:https://www.forbes.com/sites/niallmccarthy/2017/03/13/the-massive-cost-of-americas-crumbling-infrastructure-infographic/#c415ebb3978e]

[3] Brumbaugh, Griffin, *ASCE News*, 2017. [web-link: http://news.asce.org/5-ways-underfunding-infrastructure-affects-you/]