Kyle Brown – Graduate Research Plan Statement:

Introduction

Every day, millions of people stake their lives on the structural integrity of the aircraft carrying them. Our confidence in these critical engineering structures rests just as heavily on the quality of aircraft design and manufacture as on the efficacy of aircraft inspection and maintenance procedures. As aerospace manufacturers increasingly incorporate advanced materials into their aircraft, the need for advanced non-destructive inspection technology grows in parallel. More than ever, we need the ability to rapidly obtain high-fidelity information about the condition of critical structures.

Background

Imagine pressing a button and watching a fleet of multirotor UAVs swarm around an aircraft and intelligently sweep scanning lasers over every inch of the plane's external surface in the course of a single hour. Imagine watching a 3D model of the target structure materialize on a computer screen, with superimposed scan data appearing in real time on the model's surface as the UAVs perform their scanning tasks. Locations of cracking, corrosion or delamination would appear bright red based on local ultrasonic signatures. Now imagine watching it all over again, but this time the target is a bridge, a wind-turbine, a boat, or an oil platform.

Until recently, the implementation of such a system would have been infeasible for the simple reason that no scanning technology was both fast enough *and* precise enough. In 2014, the Los Alamos National Laboratory revealed a revolutionary technology dubbed Acoustic Wavenumber Spectroscopy (AWS). AWS utilizes laser Doppler vibrometry measurements of a structure's full-scale steady state ultrasonic response in order to rapidly image hidden structural defects like corrosion, delamination and cracks. AWS is safe, noncontact, and capable of scanning at a rate 300 m^2/hr—*30 times faster* than the closest competing technology [1]. In other words, scanning technology is finally fast enough to warrant an aerial scanning platform.

Hypothesis

I propose that a rapid laser scanning technology can realistically be implemented on board an unmanned aerial vehicle. This mobile scanning platform will be able to access and scan any location on a structure from multiple angles. This will facilitate a more comprehensive analysis than is currently possible with a fixed system by enabling the behavior of each scanned point on the surface to be evaluated in terms of both the out-of-plane *and* in-plane components of vibration. Such a system can only be implemented if the following objectives are met:

- Develop a **scan reconstruction technology** that will measure and *accurately map* ultrasonic scan data to the surface of the target structure *based on 3D geometry of the target structure and the reported position and pose of the scanning platform*
- Develop an **airborne platform** that will *accurately report its exact position and pose relative to a target structure* while intelligently flying an appropriate scan trajectory

As each objective is a significant endeavor, I will structure my research activities in such a way that I will be able to pursue these objectives independently of each other and in parallel.

Research Plan

Having spent the last summer at LANL working on a handheld laser scanning system, I am familiar with many of the challenges that will be associated with accurately overlaying scan data on a 3D structure. Mapping the scan data to the structure is a Simultaneous Localization and Mapping (SLAM) problem, and depends both on structure geometry as well as scanner position and orientation. Current research efforts use machine vision techniques to address similar issues [2,3]. Bringing to bear my research experience in wave mechanics and machine vision, I will expand on these SLAM techniques by additionally incorporating the measured wave field data (coupled with wave propagation models) into the optimal 3D scan reconstruction. I believe this integration will lead to a significant improvement in the reconstruction accuracy.

To accomplish the reconstruction objective, I'll start with a ground-based, gimbaled turntable on which to mount scan targets. In this way, the mapping and 3D reconstruction research can advance independently of the UAV development. As my research progresses, I will successively add degrees of freedom to the scanner-target relationship until the laser system can continuously move with six degrees of freedom relative to the target during operation.

In the meantime, I will also work on researching and protoyping various UAV configurations. My experience with the Robot Operating System (ROS) will prove useful here. I'll seek to employ undergrad students to help with time-consuming UAV management. When the 3D reconstruction research and the UAV development reach maturity, I will focus my efforts on combining them and testing the aerial scanning platform on actual structures.

The Structural Engineering program at UCSD is the ideal forum for carrying out my proposed research. Dr. Michael Todd's lab is known for its work with ultrasound, NDE, optics, and UAVs. UCSD's partnership with LANL means that I will have continued access both to the personnel and to the resources at the Engineering Institute. At UCSD, I will have the latitude to compose a curriculum specifically tailored to the unique demands of my research. Indeed, the Structural Engineering program not only encourages, but *requires* interdisciplinary study. Alongside the core courses in topics like acoustics, advanced instrumentation and statistical signal processing, I'll be taking classes in control theory, robotics, computer vision, and embedded systems programming.

Broader Impact of Proposed Research

It is difficult to overstate the value and impact of this research. Aerial scanning ultrasound technology will drastically increase the speed and effectiveness of aircraft inspection. These benefits will extend to wind turbine blades, radioactive storage containers, and other structures that are critical to our national energy infrastructure and security. This technology will enhance and accelerate NDE research by enabling more frequent and comprehensive inspection. It will also open the door to implementing rigorous inspection policies for aging structures that have hitherto been impractical/impossible to regularly test. Software developed in association with the novel UAV controls and imaging system will be contributed to ROS and OpenCV. This will enable other researchers to participate in and build on my efforts and discoveries.

I will also specifically seek to get kids excited about engineering. For younger students, I hope this will involve demonstrating my UAV (or at least showing videos) at elementary, middle and high schools. All jokes aside, what's cooler to a ten-year-old than a flying machine with a laser on it? For some kids, especially those from a disadvantaged background, this kind of demonstration will be a defining experience. If I can inspire even one child to chase her dreams and become and engineer, I will have been successful in this outreach endeavor. I'll seek to employ college and high-school students for tasks like building a gimbaled turntable, running scan experiments, and perhaps even some Ultrasonic FEA modeling. After all, a small "taste" of research is what convinced me three years ago to pursue a PhD.

[1] Flynn, E.B., Jarmer, G. J. (2013). High-Speed, Non-Contact, Baseline-Free Imaging of Hidden Defects Using Scanning Laser Measurements of Steady-State Ultrasonic Vibration. *9th International Workshop on SHM, V1*

[2] Bailey, Tim, Hugh Durrant-Whyte. "Simultaneous localization and mapping (SLAM): Part II." *IEEE Robotics & Automation Magazine* 13.3 (2006): 108-117.

[3] Montemerlo, Michael, et al. "FastSLAM: A factored solution to the simultaneous localization and mapping problem." *AAAI/IAAI*. 2002.