Building an Autonomous Civil Structure Inspection System by Leveraging Material Recognition and Fiducial Marker Localization

Keywords: Material Recognition, Planar Target Tracking, Computer Vision, Robotics

I propose the investigation of autonomous quadrotor robots for the inspection of civil structures such as bridges, tunnels, railroad tracks, and buildings. I hypothesize that through the use of fiducial marker localization and material recognition, an autonomous quadrotor system can scan a surface while identifying potential material faults.

Autonomous and semi-autonomous solutions have been proposed and deployed for disaster relief missions [1,2] and have shown promise in their utility for inspecting damaged piers and sea walls [2]. In all these works however, the deployed systems' sole purpose was image collection. My goal is to expand the responsibilities of an autonomous inspection system to include the automatic identification of potential structural deficiencies. I plan to address this goal by tailoring a new fiducial marker localization system to quadrotor robots and by augmenting current material recognition methods to utilize pose information for learning and classification.

Research Plan: I plan to build an autonomous quadrotor inspection system under the guidance of Dr. Derek Hoiem, Dr. Tim Bretl, and Dr. Mani Golparvar-Fard. Calling upon the expertise of Dr. Derek Hoiem and Tim Bretl, I hope to improve current fiducial marker pose estimation by tailoring a new system to the needs of a quadrotor. Then, building on the previous work of Dr. Mani Golparvar-Fard with information modeling for structure assessment [3], I plan to leverage pose estimates to improve material recognition accuracy and robustness to perspective in real world scenes.

Fiducial Marker Localization: Fiducial Markers are artificial planar targets that are placed in the scene, are easily detected, and provide a stable method for pose estimation. They have become popular for augmented reality applications and have been designed to meet those needs [5]. I plan to investigate how a new fiducial marker system can be tailored to the limiting factors of a quadrotor: computational power and unconstrained motion. Based on my preliminary experimentation using a state of the art fiducial marker, AprilTAG [5], I saw that % of computation time was used simply to detect the marker in the scene. I believe that this can be greatly improved by leveraging certain properties of both the quadrotor and our intended applications. For starters, current marker systems emphasize the generation of thousands of unique markers with robust detection for each. This need for many unique markers stems from augmented reality applications and is a wasteful feature for inspection tasks where the system is constrained to a specific target surface. In addition, to remain generally applicable, state of the art systems do not leverage color information for marker detection; however, since I plan to leverage color for material recognition, it becomes appropriate to utilize unnatural scene colors for quicker marker detection. Moreover, civil structures tend to be characterized by lines, corners, and geometric shapes. This spectrum creates a unique pattern in the frequency domain, and would be easily differentiable from a marker that exhibited stochastic properties.

Once a marker has been detected, the remaining computational time is spent estimating the pose of the camera relative to the marker. Current systems are robust to a full 360 degree of in-plane rotation. Since the quadrotor will never fly upside down, however, there is no need for this level of robustness. Thus, by estimating pose with constrained motion possibilities, faster computation times should be achievable. Furthermore, since the possible motion is limited, the estimation accuracy should also increase.

Material Model for Fault Recognition: Current material recognition research has demonstrated that material models can be learned from color and texture information [6,7]. Unfortunately, fault recognition has rarely been considered because material recognition has yet to expand successful results into real world scenes. I plan to bridge this gap by incorporating geometric information as part of the material models and recognition process. In particular, I believe that camera pose information can be used to learn more descriptive material models. For example, consider a straight forward, close up view of a brick wall. This close view yields color information of the brick and mortar and porous texture information. As we back away from the brick wall, information about the texture and color is lost as the wall begins to look more like a brown or red blob. On the other hand, if we shift left or right parallel to the wall and rotate to view the same portion of the wall, perspective distortion starts to take effect by slanting the horizontal lines of the mortar on the brick wall. By modeling these perspective induced phenomenon, I hope to achieve successful material recognition from real world scenes. In addition, because my proposed models encode perspective information, I hope to back out a pose estimate during the recognition process, improving the estimate produced by my fiducial marker system.

Expected Results: I will produce a new fiducial marker system that is tailored to quadrotor applications by leveraging color and frequency as well as motion characteristics inherent to quadrotors. I expect to improve upon current methods in terms of computation time, detection accuracy, and pose estimation accuracy. In addition, I will build upon previous learning approaches to material recognition by incorporating pose as an additional feature. I expect to produce comparable results on material swatch testing and superior results on real world scene tests; thereby demonstrating the viability of geometric and pose information for material recognition. I will use the AscTec Pelican Quadrotor platform for testing and will produce results verifying that my system is capable of scanning a surface, understanding the materials of that surface, and identifying potential material faults.

Intellectual Merit: Quadrotors have become a popular platform for researchers due to their high maneuverability, small size, and applicability in both military and commercial sectors [8]. Many researchers hope to use quadrotors as a tool for their own research applications, however it can be difficult and time consuming to implement autonomous flight. A fiducial marker system tailored to quadrotor applications would enable these researchers to easily set up a control system that is also lightweight enough to facilitate additional computation. Furthermore, material recognition in real world scenes have proven to be difficult [7]. My method attempts to address this difficulty by incorporating pose information into the material models. In addition, my method provides the capabilities for backing out camera pose during the recognition.

Broader Impacts: Civil structures require many hours of inspection and repair to ensure that they remain structurally sound and safe for use. In many cases, the inspection alone requires complex machinery and countless man hours. Consider the bridge shown in figure 1. This type of bridge is quite common in the United States, yet still requires several workers and expensive machinery to inspect. Due to these limitations, it is often financially infeasible for government budgets to afford the proper inspections and maintenance. In fact, there are over 66,000 (one in nine or 11%) bridges in the United States that have been categorized as structurally deficient, and as the national bridge infrastructure ages, this condition will only worsen [9]. Providing an autonomous solution will greatly reduce the costs of inspections to bridges, and can be easily extended to tunnels, railroad tracks, and exterior building inspections. Greater flexibility with government budget will allow for increased inspection frequency and maintenance, resulting in improved overall structural integrity of civil structures.

As a PURE mentor for undergraduate research at the University of Illinois, I have already incorporated four undergraduates into preliminary work with autonomous civil structure inspection. Specifically, one group of two students is implementing a tablet pc application to display the video stream from the quadrotor so that a human user can annotate and influence inspections as they progress. Another group of two students has been testing existing fiducial marker systems as we try to pinpoint bottlenecks in the detection and pose estimation processes. I am particularly motivated to continue incorporating undergraduates in my research because I greatly benefited from the guidance of graduate student mentors during my past research experiences.

References: [1]Post-disaster imagery collection utilizing a multi-rotor unmanned aerial vehicle [2] Cooperative use of unmanned sea surface and micro aerial vehicles at Hurricane Wilma [3] Dimitrov, A., Golparvar-Fard, M. (2013). "Vision-based Material Recognition for Automated Monitoring of Construction Progress and Generating Building Information Modeling from Unordered Site Image Collections". Elsvier Journal of Advanced Engineering Informatics (in review) [4]ARTag [5] AprilTAG [6]Varma Materials [7] MIT Materials [8] Quadrotor Survery [9]The Fix we’re in for