Characterization and Prognosis of Multirotor Failures

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1. **Abstract –** Multirotor (MR) unmanned aviation systems are becoming increasingly popular. The cost of these vehicles has dropped substantially, and a wide variety of models are now readily commercially available. There are numerous technical challenges and safety issues associated with the commercial use of MR unmanned aviation systems. If MR vehicles are ever to be used for commercial applications it is necessary that we become familiar with the failure modes experienced by MR's, and develop tools to detect, characterize, and prognose these failures before they become a safety concern. Since the goal of these technologies is to use them in an autonomous, unattended mode, it is necessary that a structural health monitoring (SHM) technology be developed to automatically detect incipient damage before failure occurs. This project will focus on using the UCSD/LANL developed rotating machinery structural health monitoring toolbox, SHMTools, to begin the process of characterizing the failure modes experienced by MR's, detect and characterize failures in MR vehicles, and identify signatures that can be used in prognosis models.

2. Project Outline

a. **Goal –** Initial work will focus on cataloging and characterizing failure modes of MR's including motor failure, propeller damage, bolt and fastener loosening, and fatigue damage. The project will seek a novel, practical hardware and software solution to detect incipient damage allowing for mission abort prior to catastrophic failure. Successful development of damage prognosis techniques will enable missions to continue under safe operating conditions in the presence of damage by predicting the remaining life and usage of damaged components.

b. **Motivation –** Safety is one of the top concerns that must be addressed. MR's have a number of potentially hazardous components. There are high-speed motors and propellers that can induce vibrations in the airframe causing it to suffer from loosened bolt or fatigue damage. The propellers themselves can also be nicked and suffer damage as they complete their flight plans. Motor bearings can wear out causing loss of propulsion. The lithium batteries commonly used as power sources represent a potential fire hazard. This is particularly dangerous if an autonomous MR crashes over a dry forest introducing the possibility of a fire. MR's also contain electronic speed controllers (ESCs) that can be damaged during over-use conditions. These concerns are a major factor in determining the safety and liability risk of employing MR vehicles in commercial application. Furthermore, a number of countries have legislation in place to allow the use of unmanned aviation systems for commercial use. It is anticipated that such legislation will exist in the US within the next couple of years and will likely be impacted by the concerns above and available technologies for mitigating failure.

c. **Procedure –** To complete this project, students will need to investigate a variety of sensing technologies and analysis methods to detect and quantify the numerous failure modes of MR devices. Extensive use will be made of the structural health monitoring toolbox (SHMTools) software developed by the Engineering Institute to quickly prototype and evaluate potential damage metrics. Successful damage prognosis will further require development of novel predictive models and quantifiable methods for estimating performance and determination of safe operating parameters for mission completion.

3. Background Literature

- A. Raptopoulos, “Matternet,” June 2013, http://matternet.us/ted/
- Worden, K., Farrar, C.R., Manson, G., and G. Park, “Fundamental axioms of structural health monitoring”, Proceedings of 5th International Workshop on Structural Health Monitoring, 2005, pp. 26–41.
- Lebold, M., McClintic, K., Campbell, R., Byington, C., and K. Maynard, “Review of Vibration Analysis Methods for Gearbox Diagnostics and Prognostics,” Proceedings of the 54th Meeting of the Society for Machinery Failure Prevention Technology, 2000, p. 623-634.
- Flynn, E. B., Kpotufe, S., Harvey, D., Figueiredo, E., Taylor, S., Dondi, D., Mollov, T., Todd, M. D., Rosing, T. S., Park, G., and C. Farrar, “SHMTools: A new embeddable software package for SHM applications,” Proceedings of SPIE2010, 7647, 2010.

4. Week by Week Plan

Week	Task
1	Project, hardware, and software introduction; brainstorming
2	Instrumentation setup and preliminary data collection
3	Preliminary analysis; identify failure modes; develop test plan
4	Execute test plan and develop damage metrics
5	Execute test plan and develop damage metrics
6	Evaluate damage metrics; develop novel prognosis models
7	Evaluate prognosis models; begin paper draft
8	Finalize analysis; prepare presentation
9	Final presentation; complete paper draft

5. **Real World Design Issues as a Project Consideration**
   a. Weight: proposed hardware must not occupy a significant portion of the MR's total lift capacity
   b. Power: sending and monitoring system must not represent a significant portion of total power budget
   c. Operator Feedback: what information and interface would be most useful for MR operator?

6. **Equipment Requirements**
   - Multirotor and spare parts
   - Sensors: accelerometers, load cells
   - Standard multi-channel data acquisition

7. **Software Requirements**
   - MATLAB (v7 or later)
   - SHMTools and mFUSE (unreleased versions 0.3)