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Airborne Wind Energy System: Flight Data Analysis Using System Identification and Machine Learning, and Control of Launching

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論文名 ： Airborne Wind Energy Systems: Flight Data Analysis Using System Identification and Machine Learning, and Control of Launching

（空中風力発電システム：システム同定と機械学習による飛行データ解析，ならびに，離陸制御）

Title

区　分 ： 甲 (Kou)

論文内容の要旨

Thesis Summary

This thesis investigates several aspects of a new paradigm for utilizing wind energy, namely harvesting energy from wind at high altitudes, conveniently called the paradigm of Airborne Wind Energy (AWE). Systems built according to this paradigm (AWE systems) constitute an emerging technology for harvesting energy from wind of steady high speed without the need of a heavy tower or foundation; such as the wind turbine used for generating energy from surface-level wind. The most prominent part of an AWE system is a device or vehicle flying in the air while being mechanically connected to the ground (e.g., tethered kites or tethered balloons, which employ a tether for ground connection) Such an AWE system allows the beneficial exploitation of the relative velocity between the airmass of the AWE vehicle and the ground.

Our work starts with modelling and simulation of the tether subsystem using the lumped mass model. We built our own in-house code.

We demonstrate the 7 kW kite system of Kyushu University, including the system's design, tests, and experimental results. The kite system consists of an inflatable wing with a fixed tether length. The kite is controlled by a small device, kite control unit (KCU), as a hardware-in-the-loop (HIL). This technique is utilized to develop and perform the real-time flight test of the kite. It provides an effective algorithm by adding the complexity of the system under control. Several tests had been performed to analyze the kite performance, and tension forces result of those tests are presented in different truck speeds and flight cases.

After collecting the data, we came to post-processing and data analysis step. We used System Identification (SI) to come up with a simple model for the kite using Plackett's algorithm, which is based on one input (roll) and the output tension. So, in the future, we could apply and implement any control

technique to stabilize the kite in a real-time flight.

Expanding the analysis by adding more features, we made a detailed sensitivity analysis; data-based and model-based. The resultant highly correlated features with the output feature (tension) were stated. Then we apply several Machine Learning (ML) algorithms to predict the value of the tension forces, so we could know the power production amount in different cases in the future. The Neural Network (NN) algorithm proves a clear success in fitting the data of AWE towing tests.

The thesis presents another notable contribution along a different line of research pertaining to another flying vehicle type. We observe that soft kites may have some problems during launching, an alarming shortcoming that led many pioneering AWE companies to start exploring rigid wing flying devices, with an eye on simplifying the process of vertical take-off and landing (VTOL). To catch up with the promising research concerning such devices, we present a detailed study that concerns the control and simulation of the transition phase of the AP-2 aircraft, recently developed by a leading AWE company, namely, Ampyx Power. This study is an important prelude to a complete study of the overall pumping cycle, including not only the transition phase, but also both its preceding phase (VTOL phase) and succeeding phase (flight-mode phase).

Thesis Organization:

The work done in this thesis could be divided into three parts; Modelling & Control, Project & Experimental work and Data Analysis using system identification (SI) & Machine Learning (ML).

In the first part, we modelled a kite system using the lumped mass model in Appendix A. Due to launching problems for soft kites, we go for rigid aircraft modelling in Chapter 5 and give a detailed optimal control of the transition phase.

In the remaining two parts, we introduce Kyushu kite project and experiments in Chapter 2. Then we benefit from the collected data of our early flight tests to identify the kite behaviour using system identification in Chapter 3. After that, in Chapter 4, we enhance the collected data and we added more features which used to train a machine learning algorithm for power prediction, and this was the first attempt in the AWE community to apply ML algorithms in AWE technology. Finally, we concluded the thesis with Chapter 6.