# Preface

This book is based on my experience with the control systems of antennas and radiotelescopes. Overwhelmingly, it is based on experience with the NASA Deep Space Network (DSN) antennas. It includes modeling the antennas, developing control algorithms, field testing, system identification, performance evaluation, and troubleshooting. My previous book[1] emphasized the theoretical aspects of antenna control engineering, while this one describes the application part of the antenna control engineering.

Recently, the increased requirements for antenna/telescope pointing accuracy have been imposed. In the case of DSN antennas, it was the shift from the S-band (4 GHz) and X-band (8 GHz) communication to Ka band (32 GHz). On the other hand, the Large Millimeter Telescope will operate up to 200 GHz, which requires extremely accurate pointing. These requirements bring new challenges to the antenna control engineers. Classical PI controllers cannot assure the required accuracy, while model-based controllers (LQG, and $H_\infty$) increase the antenna accuracy by a factor of 10. These controllers are new for antenna/telescope engineering. This book describes their development and application.

The book is addressed primarily to the antenna, telescope, and radiotelescope engineers, engineers involved in motion control, as well as students and researches in motion control and mechatronics (antenna is a combination of mechanical, power, and electronics subsystems). The book consists of two parts: Modeling (Chapters 2–5) and Control (Chapters 6–13).

In the modeling part, Chapter 2 describes the development of the analytical model of an antenna, including its structure (finite-element model) and drives (motors, reducers, amplifiers). This modeling is useful in the design stage of an antenna. Chapter 3 describes the determination of the antenna model using field tests and the system identification approach. These models are quite accurate, and are used in the development of the model-based controllers. Because the order of models (analytical as well as from the identification) is often too high for the analysis and

[1] Gawronski W. (2004). *Advanced Structural Dynamics, and Active Control of Structures.* Springer, New York.

for controller implementation, it is reduced to a reasonable size while preserving the critical properties of the full model. Chapter 4 briefly describes the reduction techniques as applied to antennas and telescopes. Finally, the wind disturbance models are developed in Chapter 5. Wind is the major disturbance source for antennas and telescopes. The steady (or static) wind model is presented, based on wind tunnel data and confirmed by the field data. Also, three wind gusts models are presented.

The control part presents the performance criteria and shows how to transform the antenna model to be the most suitable for controller tuning. In Chapter 7, the book presents the development, properties, and limitations of the PI controller. It shows the impact of the proportional and the integral gains on the antenna closed-loop performance. It also analyzes the limits of the PI controller performance. Chapter 8 describes the tuning process of the LQG controller. It analyzes the performance of the LQG controller, including its limits. It presents the graphical user interface (GUI) that allows us to tune the antenna LQG controller without analysis, but by playing with the GUI sliders and buttons ("LQG for dummies"). It is shown in this chapter that the performance of the LQG controller depends on its location: either at the position loop or at the velocity loop, or at both. It shows also that in the case of the 34-m DSN antennas the servo error with LQG controller decreased by a factor of 6.5 when compared to the PI controller. In Chapter 9, $H_\infty$ controller tuning is presented: gain determination, closed-loop equations, limits of performance. In the following chapter, the non-linear control issues are addressed. The velocity and acceleration limits often interfere with antenna dynamics. Two solutions are proposed: a command preprocessor, and the anti-windup technique. Friction is the source of a deteriorated pointing. Dither can be a solution, as presented in this book. Finally, gearbox backlash is described and the counter-torque solution to minimize it is presented.

A typical antenna control system consists of two loops: velocity and position loops. A single-loop solution is studied in Chapter 11. The antenna control system uses the encoder measurements to estimate RF beam position, but it is only a rough estimate. The encoder measures the antenna angular position at its location, which is different from the RF beam location; thus, antenna structural compliance is the source of the error. Chapter 12 describes two techniques to control the RF beam position: monopulse and conscan. Finally, in Chapter 13 we describe an open-loop RF beam control: the look-up table that corrects for the uneven azimuth track that impacts the RF beam position.

Analysis is a skill. However, even complex theories and the supporting analysis are, in a sense, simple because they assume certain properties that simplify the analysis, or to make it possible. Still, although the theoretical path delivers an answer, engineers have to ask if the answer is applicable to the real environment.

Engineering is an art. Some aspects of engineering can be described rigorously by theoretical analysis, but not all. There are cases where engineering reality does not satisfy analytical assumptions. Hence, engineering solutions are often ad hoc solutions. This engineering dilemma is summarized by Scholnik: "Who cares how it works, just as long as it gives the right answer."

The art of engineering often includes features that theoretically cannot work. For example:

- LQG controllers cannot be applied to antennas, because the antenna model have poles at zero (rigid-body mode). But the LQG controllers do control the antennas.
- The noise in the tuning of the LQG controller should be the Gaussian noise, which is not the case of antennas or telescopes.
- Rigidly applied model reduction algorithms do not produce the best reduced model (best in terms of the antenna performance).
- Every LQG controller is an optimal controller, but not every one is acceptable.
- In the $H_\infty$ controller tuning the plant uncertainity should be either additive or multiplicative. The antenna uncertainity, which depends on its elevation position, is neither additive nor multiplicative.

Despite these difficulties, engineers succeed in developing acceptable control systems, including antennas and telescopes.

Readers who would like to contact me with comments and questions are invited to do so. My e-mail address is wodek.k.gawronski@jpl.nasa.gov or w.gawronski@sbc global.net.

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