Chapter 2
Guidance and Control of Formation Flying Spacecraft

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Abstract A key element of NASA’s future space exploration is high precision formation flying (FF) for space interferometry. Precision FF has never been attempted before and poses new and significant challenges to the underlying control system. While the guidance and control (G&C) methodologies of single spacecraft for traditional planetary flyby and orbiter missions are well-understood, the G&C of FF missions is fundamentally different. The FF systems require new control systems, architectures, and greater levels of autonomy to meet expected precision performance in the presence of environmental disturbances, plant uncertainties and more complex system interactions. This chapter will trace the motivation for these changes and will layout approaches taken to meet the new challenges.
2.1 Introduction

Formation flying spacecraft refers to a set of spatially distributed spacecraft, capable of autonomously interacting and cooperating with one another (Figure 2.1). Many of NASA’s future Earth and Space science missions involve formation flying. For Earth science applications, formation-flying spacecraft will enable a next generation of instruments for understanding the Earth and the effect of natural and human-induced changes on the global environment. For example, formations will enable distributed sensing for Earth gravity mapping, distributed atmospheric data collection, magneto-spheric studies, co-observations, and global communication systems. It will become possible to deploy large numbers of low-cost, Earth-orbiting miniaturized spacecraft/instruments with the opportunity for introducing new members to the formation for expansion, for upgrading technologies, or to replace a failed member. Similarly, several space science missions (e.g., Terrestrial Planet Finder, Interferometers (see Figure 2.2) and Terrestrial Planet Imager (103)) include distributed instruments such as a large phased array of lightweight reflectors and antennas and long, variable baseline space interferometers. The group of collector and combiner/integrator spacecraft would form a variable-baseline optical space interferometer for a variety of science applications from exo-Earth detection to imaging the event horizon of a black hole. The elements of the formation flying system must act collaboratively as a single unit, which represents a common system to perform a task. The quality of the collective behavior of all the spacecraft in the formation will determine the quality and the magnitude of the science return. Formation flying spacecraft must conform to extremely stringent control and knowledge requirements. Such precise requirements have never existed before. For example, the control system for space interferometry, for example, must provide precision station-keeping from coarse requirements (relative position control of any two spacecraft to less than 1 cm, and relative attitude control of 1 arcmin over a large range of separation from a few meters to tens of kilometers) to fine requirements (nanometer relative position control, and .01 milliarcsec relative attitude control). Conformance to such precise performance metrics presents new challenges, not only in the areas of guidance, estimation, and control, but also in the areas of dynamic modeling of the formation flying spacecraft and their environment. It will be crucial to better

Fig. 2.1 Earth Orbiting and Deep Space Formation Flying Spacecraft Interacting with One Another for Co-observations