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Autonomous and Autonomic Systems: With Applications to NASA Intelligent Spacecraft Operations and Exploration Systems

With 56 Figures



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Preface

In the early 1990s, NASA Goddard Space Flight Center started researching and developing autonomous and autonomic ground and spacecraft control systems for future NASA missions. This research started by experimenting with and developing expert systems to automate ground station software and reduce the number of people needed to control a spacecraft. This was followed by research into agent-based technology to develop autonomous ground control and spacecraft. Research into this area has now evolved into using the concepts of autonomic systems to make future space missions self-managing and giving them a high degree of survivability in the harsh environments in which they operate.

This book describes much of the results of this research. In addition, it aims to discuss the needed software to make future NASA space missions more completely autonomous and autonomic. The core of the software for these new missions has been written for other applications or is being applied gradually in current missions, or is in current development. It is intended that this book should document how NASA missions are becoming more autonomous and autonomic and should point to the way of making future missions highly autonomous and autonomic. What is not covered is the supporting hardware of these missions or the intricate software that implements orbit and attitude determination, on-board resource allocation, or planning and scheduling (though we refer to these technologies and give references for the interested reader).

The book is divided into three parts. The first part gives an introduction to autonomous and autonomic systems and covers background material on spacecraft and ground systems, as well as early uses of autonomy in space and ground systems. The second part covers the technologies needed for developing autonomous systems, the use of software agents in developing autonomous flight systems, technology for cooperative space missions, and technology for adding autonomicity to future missions. The third and last part discusses applications of the technology introduced in the previous chapters to spacecraft constellations and swarms, and also future NASA missions that will need the

discussed technologies. The appendices cover some detailed information on spacecraft attitude and orbit determination and some operational scenarios of agents communicating between the ground and flight software. In addition, a list of acronyms and a glossary are given in the back before the list of references and index.

In Part One of the book, Chap. 1 gives an overview of autonomy and autonomic systems and why they are needed in future space missions. It also gives an introduction to autonomous and autonomic systems and how we define them in this book. Chapter 2 gives an overview of ground and flight software and the functions that each supports. Chapter 3 discusses the reasons for flight autonomy and its evolution over the past 30 plus years. Chapter 4 mirrors Chap. 3 for ground systems.

In Part Two, Chap. 5 covers the core technologies needed to develop autonomous and autonomic space missions, such as planners, collaborative languages, reasoners, learning technologies, perception technologies and verification and validation methods for these technologies. Chapter 6 covers designing autonomous spacecraft from an agent-oriented perspective. It covers the idea of a flight software backbone and the spacecraft functions that this backbone will need to support, subsumption concepts for including spacecraft functionality in an agent context, and the concept of designing a spacecraft as an interacting agent. Chapter 7 covers the technologies needed for cooperative spacecraft. It starts by discussing the need for cooperative spacecraft, a model of cooperative autonomy, mission management issues for cooperation, and core technologies for cooperative spacecraft. Chapter 8 covers autonomic systems and what makes a system autonomic, why autonomicity is needed for future autonomous systems, and what functions would be needed to make future missions autonomic.

Part Three starts with Chap. 9, which discusses spacecraft constellations, cooperation between or among the spacecraft in the constellation, difficulties in controlling multiple cooperative spacecraft, and a multiagent paradigm for constellations. Chapter 10 gives an overview of swarm technology, some example missions that are being proposed that use this technology, and issues in developing the software for swarm-based missions. Chapter 11 discusses some future missions that NASA is planning or developing conceptually. This chapter discusses how the technology discussed in the previous chapters would be applied to these missions, as well as additional technology that will need to be developed for these missions to be deployed.

The Appendix offers additional material for readers who want more information concerning attitude and orbit determination and control, or concerning operational scenarios of agents communicating between the ground and flight software. This is followed by a list of acronyms used in the book and a glossary of terms. All references are included in the back of the book.

There are three types of people who will benefit from reading this book. First are those who have an interest in spacecraft and desire an overview of ground and spaceflight systems and the direction of related technologies.

The second group comprises those who have a background in developing current flight or ground systems and desire an overview of the role that autonomy and autonomic systems may play in future missions. The third group comprises those who are familiar with autonomous and/or autonomic technologies and are interested in applying them to ground and space systems.

Different readers in each of the above groups may already have some of the background covered in this book and may choose to skip some of the chapters. Those in the first group will want to read the entire book. Those in the second group could skip Chap. 2 as well as Chaps. 3 and 4, though the latter two may be found interesting from an historical view. The third group of people could skip or skim Chap. 5, and though they may already be familiar with the technologies discussed in Chaps. 6–8, they may find the chapters of interest to see how AI technologies are applied in the space flight domain.

We hope that this book will not only give the reader background on some of the technologies needed to develop future autonomous and autonomic space missions, but also indicate technology gaps in the needed technology and stimulate new ideas and research into technologies that will enable future missions possible.

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