AN INTRODUCTION TO GNSS

A primer in using Global Navigation Satellite Systems for positioning and autonomy

THIRD EDITION

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“Their 'we-do-it-not-because-it-is-easy-but-because-it-is-hard' attitude inspired me.”

–**Dr. Robert Thirsk**, Astronaut, doctor, engineer

FOREWORD

The urge to explore is innate — and space presents humanity with a boundless frontier to be explored. For myself, the notion of space exploration was planted in my mind when I was a child. Growing up in the 1960s, I followed the exploits of the early astronauts who boldly went where no one had gone before. What courage!

I watched in awe as Armstrong and Aldrin guided their spiderly lunar module down to a pin-point landing on the Moon and then, a few hours later, bounded about its magnificently desolate surface. Their “we-do-it-not-because-it-is-easy-but-because-it-is-hard” attitude inspired me. In later years, I jumped through all the academic and career hoops that might someday help me realise my own dream of spaceflight.

Beyond this self-indulgent motivation to explore the great unknown, the development of space over the past decades has brought about pragmatic and untold benefits to society at large. We take for granted that many everyday services are enabled by space technology — how we communicate, how we know whether to grab an umbrella as we step out the door in the morning, even how we’re entertained. Space even affords a unique laboratory setting to advance research in ways that aren’t possible on Earth.

During both my forays into space, I relied upon positioning and automation technologies to complete my missions. During ascent of the shuttle, for example, data from the vehicle’s three inertial measurement units were fed to the flight software steering the engine gimbals so that we arrived in space at a targeted position and velocity.

On orbit, I worked with science teams on the ground to conduct a host of international investigations — from medical science to fluid physics to robotics. Whether crystalising a large protein molecule associated with a debilitating congenital illness — impossible to do on Earth due to gravity — to testing control algorithms for satellite systems using free-flying robots, every experiment provided new insights. Knowing that the data we collected would be applied to social needs on the ground brought a feeling of satisfaction and gratitude for the opportunity to serve. And the view out the spacecraft window wasn’t too bad either!

What unfolds over the next decades will be even more exciting. We will watch in wonder as the next generation of astronauts ventures farther into the solar system.

Enterprising industrialists will develop novel means to harness resources from the Sun and near-Earth asteroids to support the needs of civilization. Enhancements of existing space technologies will improve sustainability of life on Earth. In particular, new applications of autonomy and positioning technologies will transform how we grow our food, monitor the environment, manage our natural resources and transport goods about the global supply chain.

Which brings me to the subject of this book. Global Navigation Satellite Systems (GNSS) are at the heart of answering the questions: where am I and how do I get to my destination? The answers lie in precision

Aurora borealis over Alberta, Canada, taken from the International Space Station

positioning, navigation and timing (PNT) capabilities enabled by GNSS. The accuracy and speed of the technologies detailed in this book have advanced to the point where cars, ships, planes and spacecraft can know their locations in real-time with unprecedented precision. Their ready adoption across applications like mining and autonomous vehicles has been enabled by the integration of advanced sensors and increasingly sophisticated positioning solutions.

What does this have to do with sustainability? Greater efficiencies and reduced costs are achieved through autonomous operations, from self-driving transport trucks that shave hours off shipping times and enable unmanned ore transport in mining operations, to agricultural positioning technologies that ensure year-after-year repeatability in crop production.

Although I'm no longer an active astronaut, my passion for innovation guides my continuing mission to make our world a better place. One way I do that is by encouraging today's young explorers to work outside of their comfort zones, to participate in collaborative, team-oriented ventures and to pursue audacious dreams. The realisation of such dreams will only be possible when built upon a foundation of lifelong learning and advanced skills.

If you're reading this book, you've already launched on the right trajectory to this bright and sustainable future!

–Dr. Robert Thirsk

TABLE OF CONTENTS

"The massive bulk of the Earth does indeed shrink to insignificance in comparison with the size of the heavens."

–Nicolaus Copernicus

1 GNSS overview

"New ideas pass through three periods: 1) It can't be done. 2) It probably can be done, but it's not worth doing. 3) I knew it was a good idea all along!"

–**Arthur C. Clarke**, British author, inventor and futurist.

Most of us now know that GNSS "was a good idea all along" and that we are well into Clarke's third phase.

The basic concepts of satellite positioning are very easy to understand. They are so straightforward, in fact, that one of our employees was asked by his daughter to explain it to her grade 4 class.

Before the class started, he set up the following demonstration. He tacked cardboard figures of three satellites to the walls and ceiling of the classroom, as shown in **Figure 1**. Each "satellite" had a length of string stapled to it. He marked a location on the floor with a movable dot, then drew the strings down and marked where they all reached the dot. The strings now represented the distances from the dot to the individual satellites. He recorded the location of the dot and removed it from the floor.

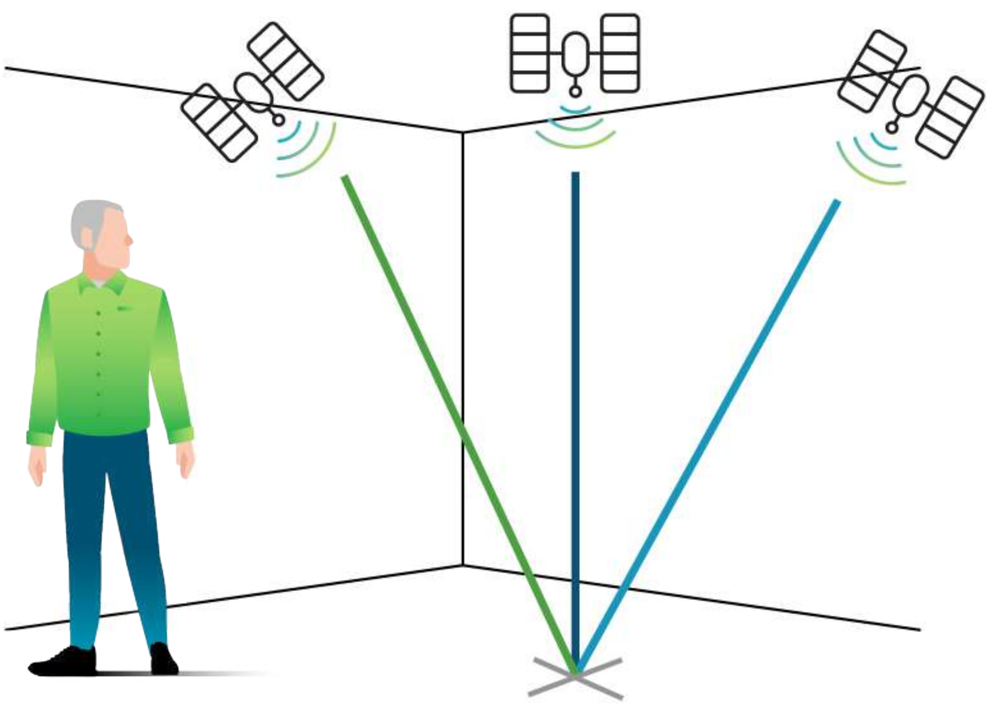

Figure 1 Classroom demonstration of GNSS positioning

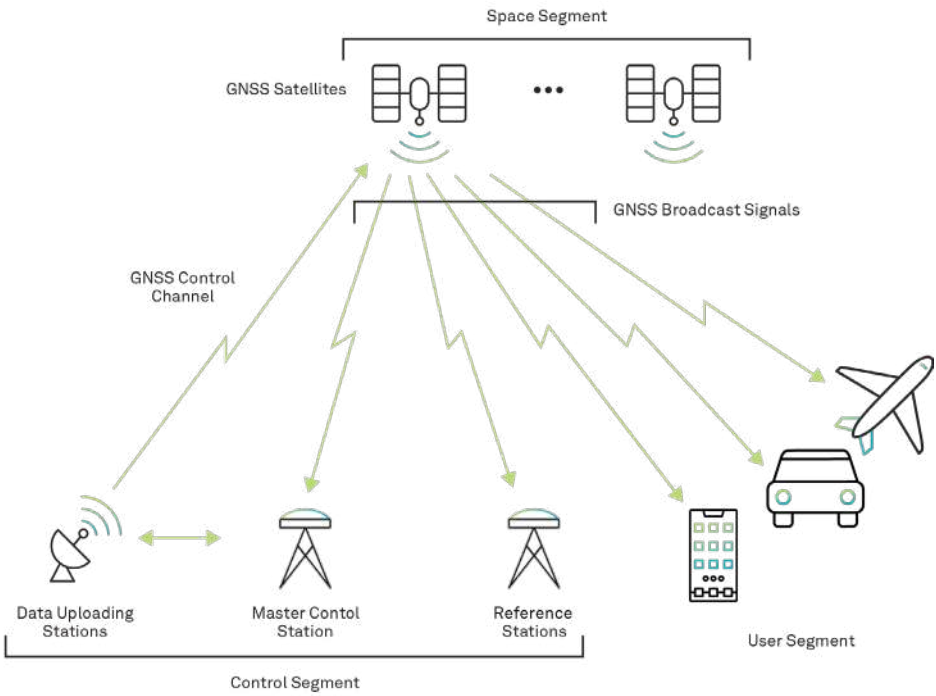

Figure 2 GNSS segments

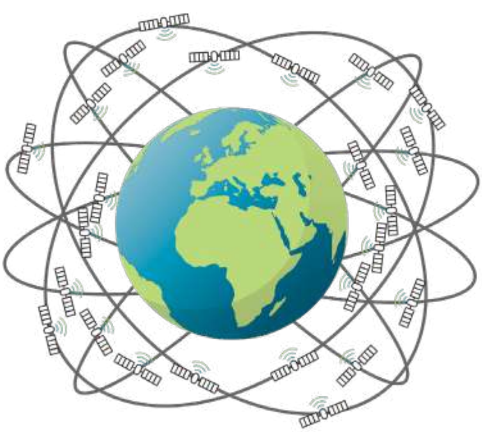

Figure 3 GNSS satellite orbits

When the students came into the classroom, our employee had them use the strings to determine the location. To do this, the students drew the strings down until the ends came together at one point on the floor. They marked this point with a movable dot and compared it with the previously marked position. They were very close. This simple demonstration showed that if you know the location of three satellites and your distance from them, you can determine your position.

The determination of position is made quite a bit more complicated by several factors: the satellites are moving, the signals from the satellites are very weak by the time they reach the Earth, the atmosphere interferes with the transmission of radio signals and, for cost reasons, the user equipment is not as sophisticated as the equipment in the satellites.

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