WLAN Positioning Systems

Principles and Applications in Location-Based Services

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Describing the relevant detection and estimation theory, this detailed guide provides the background knowledge needed to tackle the design of practical WLAN positioning systems. It sets out key system-level challenges and design considerations in increasing positioning accuracy and reducing computational complexity, examines design tradeoffs, and presents experimental results.

Radio characteristics in real environments are discussed, as are the theoretical aspects of non-parametric statistical tools appropriate for modeling radio signals, statistical estimation techniques, and the model-based stochastic estimators often used for positioning. A historical account of positioning systems is also included, giving graduate students, researchers, and practitioners alike the perspective needed to understand the benefits and potential applications of WLAN positioning.

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To my family for their never-ending love and support. A.K.

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Preface

For thousands of years, location information has been used for navigation. This has changed in the last century as advances in wireless communication and microelectronics have given birth to *mobile computing devices*. These devices enable their users to access sensing and computing capabilities from anywhere and at any time. An important consequence of such mobility is that the resource and information needs of wireless users are no longer fixed but vary with their changing location and, more generally, with their changing *context*. This has sparked a new generation of applications that employ location information to cater to the changing needs of mobile users. These applications, known as *location-based services* (LBS), are offered on top of wireless communication infrastructures to add value to existing services.

To enable and support the delivery of LBS, accurate, reliable, and realtime user location information is needed. This need has incited a new interest in positioning and tracking systems whose aim is to determine the physical coordinates of a wireless mobile device carried by a human user. The focus of this book is one class of positioning systems that employ radio signals from wireless local area networks (WLAN) for positioning. These systems are of special interest as they are able to provide high positioning accuracies in indoor and outdoor environments with minimal deployment and maintenance costs.

This book is divided into two parts. The first part focuses on topics related to the history and applications of positioning systems. The second part is dedicated to technical issues related to designing WLAN positioning systems.

Part I of the book begins by providing a brief history of positioning and navigation and the origins of radio-based positioning (Chapter 1). Next, we discuss location-based services offered in wireless networks and their applications (Chapter 2). We then present the fundamentals of positioning techniques and existing systems that enable the delivery of location-based services (Chapters 3 and 4). We examine the advantages and limitations of each positioning method and introduce WLAN-based positioning.

Part II of the book examines the technical issues involved in converting WLAN sensor readings into position estimates. We begin by discussing the nature of sensor measurements in WLAN positioning in Chapter 5 and the challenges involved in computing with these measurements. We then proceed to discuss the details of algorithms for position computation using WLAN signals in Chapter 6. In particular, we use the framework of statistical signal estimation and nonparametric methods to develop several position estimators.

Due to the noisy nature of WLAN radio signals, position estimates obtained from these signals are often noisy and associated with high uncertainty. To mitigate the adverse effects of these factors, we present two different methods. In Chapter 7, we discuss the use of pedestrian motion models in addition to radio signals to improve positioning accuracy and reliability. In particular, we examine the use of various adaptive filters for optimal fusion of information obtained from the motion model and radio signals. The second approach for combating noise and uncertainty associated with radio signals involves intelligent selection of sensors used for positioning. Chapter 8 is dedicated to discussing this topic.

Having the fundamental tools needed to address position estimation, Chapter 9 proceeds to discuss issues related to design and architecture of positioning systems. Finally, Chapter 10 concludes the book and provides directions for future research.

Part I

History and applications

1 Positioning through the ages

For thousands of years, the ability to explore the world has significantly impacted human civilization. Human explorations have enabled the interaction of cultures for the purposes of geographic expansion (for example, through war and colonization) and economic development through trade. These interactions have also played a pivotal role in an exchange of knowledge that has supported the advancement of science, the development of religion, and the flourishing of the arts throughout the world.

World exploration is largely enabled by the ability to control the movement of a vessel from one position to another. This process, known as navigation, requires the knowledge of the locations of the source and destination points. The process of determining the location of points in space is known as positioning. In this book, we use the terms location and position interchangeably to refer to the point in physical space occupied by a person or object.

Throughout history, various positioning methods have been developed including methods using the relation of a point to various reference points such as celestial bodies and the Earth's magnetic pole. More recently, the advent of wireless communications has led to the development of a number of additional positioning systems that enable not only navigation, but also the delivery of additional value-added services. The focus of this book is one such positioning method that employs wireless local area signals to determine the location of wireless devices.

In this chapter, we provide a brief account of the historical development of navigational techniques (Section 1.1). As shown in Figure 1.1, we consider two distinct periods. The first period, termed the Age of Traditional Navigation, refers to the development of navigational techniques developed to facilitate exploration and sea travel before the nineteenth century (Sections 1.2 and 1.3). The second period, termed the Age of Modern Navigation, begins with the advent of wireless communication, which ultimately gave rise to the positioning systems in commercial use today (Section 1.4).

1.1 Origins of navigation

The development of navigational science was necessitated by the human need to roam about the world. In ancient times, travel played an important role not only in exploration, but also in trade, conquest, and religious and cultural expansions. For example, colonization and the spread and development of the major religions of the world were made possible because of the human ability to move between distant locations. Much of