# Chapter 1
# Introduction

## 1.1 Why Device Free Tracking?

Object tracking is one of the primary tasks of digital life and smart computing. In the past decade, device-based tracking techniques have matured enough to provide accurate location and motion information about the target in outdoor environments. Leveraging the location-aware device, such as the GPS terminal, smart phone, or RFID transponder, computer software can detect where the target is or how it is moving. With the information, people can further perceive the trace of the target, and then take specific actions.

During perception, devices embedded in the target report the location-related information, including the direct location information and indirect location information. Direct location information can show the coordinates of the target via the device, e.g. GPS readings. The latter usually contains certain physical information that is related to the actual position of the target. For example, the received radio signals strength reported by a cellphone implicitly shows the distance between it and the access point. Obviously, direct location information is more convenient for the applications. However, it requires specific location sensors, incurring a much higher cost than the indirect location information.

In outdoor environments, device-based tracking solution is widely deployed, e.g. GPS systems. The accuracy of GPS system is satisfied with the people's localization requirement. In contrast, it is still challenging to realize accurate and reliable localization techniques for indoor applications. The reasons are twofold. First, localization infrastructure is usually not available in indoor environments due the shielding effect from the build. In such a scenario, GPS signals are weak or unreachable, leading the localization serve unavailable. The cost of redeploying a new localization infrastructure, however, may be unacceptable.

Second, the majority of indoor localization solutions are also device based. Specific devices are required to be attached with or embedded in the target, which results limits or inconvenience to the user movement. In particular, the target will be uncooperative in some applications, e.g. the intruder detection. It is impossible to attach a device to the thief in advance and then detect his movements. On the

 
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other hand, nonintrusive sensing or detection becomes popular. With the aim of minimizing or eliminating the user intervention, the nonintrusive tracking systems are promising in everyday applications.

## 1.2 Why Passive RFID Tags?

Such a nonintrusive tracking system can be achieved by deploying various sensors including passive infrared (PIR) sensors, sonic sensors, and video camera sensors. Those sensors are able to provide high accuracy and sensitivity. Deploying those sensors, together with the system, incurs high cost to large scale deployments. In practice, some infrastructures, such as Wi-Fi and RFID, have been widely deployed. The wireless signals of those systems can be disturbed by the target to be tracked. Observing and analyzing the change of those signals enable low-cost and nonintrusive detection on the location and motion of the target.

In this book, we aim to design a practical device-free tracking system using RFID tags. Many RFID based motion detection or trajectory tracking approaches have been proposed in the literature. However, most existing approaches are device-based and not suitable for intrusion detection and tracking in many applications.

Our object is to reuse existing passive RFID systems, which have been deployed in modern logistic and inventory applications, for anti-intrusion. Previous works mainly use active tags to achieve this goal. However, the cost of active tags is usually hundreds times higher than that of passive tags. Although the active tag based solutions can detect the intruder with a long range while keeping him unaware, the huge deployment cost becomes a barrier of their deployments.

The solution is inspired by our observation on the interference between tags. We observed a phenomenon that when the antennas of two passive tags are approaching to each other, one tag (or both of them) becomes unreadable due to the coupling effect among passive tags. In particular, the two tags will JUST present such a phenomenon, namely critical state, in a certain distance. Keeping the distance, reader transmission power, and other factors unchanged, the one or two tags will retain the unreadable state. The critical state can be utilized to detect the movement of nearby objects. When an object moves around the two tags, termed as Twins in the following, some extra RF signals will be reflected to the tags. The one that became unreadable can harvest those signals, which will induce currents on its antenna. Because the Twins keeps a “fragile balance” between the readable and unreadable states, a small portion of energy will be sufficient to trigger the state change, i.e. from unreadable to readable state. We define this change as a state jumping. The critical state and its sensitivity to nearby movements motivate us to leverage the Twins for localization and motion detection, enabling a device-free tracking on moving objects.

## 1.3 What Comes Next?

Chapter 2 introduces background knowledge of RFID technology, including the brief history, terminologies, frequencies, and operation patterns. Chapter 2 also reviews the related work in the literature of localization and location based service. Chapter 3 describes the observation, operating principle, and theoretical analysis of Twins. In particular, Chapter 3 details the solution on some practical problems in system design and deployment, such as the mismatch in terms of the number of unreadable tags under critical state between the theoretical analysis and real experiments. Chapter 3 also reports the discovery of a new structure-aware coupling model between adjacent tags. Chapter 4 presents Kalman filter based and particle filter based tracking schemes for tracking the object. The two schemes are designed for dense deployments. Chapter 5 extends the Twins to sparse deployment scenarios and presents a SVD based tracking scheme. A brief Afterword rounds out the main text of the book.

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