Sensing Urban Dynamics with WiFi: A Practical Guide

Juhyeon Park

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Preface

This book is a dedicated resource for anyone interested in leveraging affordable, commercially available sensors to measure non-motorized traffic in urban environments.

Quantifying non-motorized traffic—such as pedestrians and cyclists—plays a crucial role in urban studies. Understanding the flow and patterns of non-motorized traffic can inform urban planning strategies, enhance public safety, and contribute to the development of sustainable cities. Moreover, sensing technologies provide a robust and non-invasive method for capturing this vital information in real time, offering insights that traditional surveys or manual counts might miss.

The advent of the Internet-of-Things (IoT) has spurred a wave of urban sensing projects worldwide. Examples include the Array of Things (AoT) in Chicago, USA and S-DoT in Seoul, Korea, which utilize a network of sensors to gather a wide range of data.

With the increasing accessibility of DIY technologies, individuals now have the opportunity to engage with their urban environment in new and innovative ways. These tools democratize the field of urban sensing, previously the domain of expert scientists, by equipping anyone with the interest to build their own sensors.

This book is designed for those interested in understanding and monitoring non-motorized traffic. We provide comprehensive guidance on building your own urban DIY sensors for this purpose. With hands-on advice, practical examples, and detailed breakthroughs, our aim is to empower

you with the skills and knowledge necessary to contribute to the rapidly evolving field of urban sensing.

Scope of this document

This document demonstrates 1) how to build a smart sensor that detects pedestrians outdoors through WiFi sensing, and 2) how to analyze the resulting data to produce meaningful insights. This includes:

- Getting
- WiFi data preprocessing
- WiFi data analysis

Why WiFi sensing?

WiFi sensing technologies are among these tools, providing a non-invasive method for monitoring pedestrians outdoors via sensors that detect WiFi packets sent regularly by access points (APs) and WiFi-enabled devices. Most pedestrians today carry smart devices equipped with WiFi network interfaces, and each WiFi packet includes unique 48-bit addresses, known as Media Access Control (MAC) addresses, enabling a device to be tracked by multiple WiFi sensors. Many recent studies have utilized these sensing technologies to identify pedestrian movements and behaviors[1][2][3].

[1] Duives, D. C., van Oijen, T., & Hoogendoorn, S. P. (2020). Enhancing Crowd Monitoring System Functionality through Data Fusion: Estimating Flow Rate from Wi-Fi Traces and Automated Counting System Data. Sensors (Basel), 20(21). https://doi.org/10.3390/s20216032

[2] Soundararaj, B., Cheshire, J., & Longley, P. (2019). Estimating real-time high-street footfall from Wi-Fi probe requests. International Journal of Geographical Information Science, 34(2), 325-343,. https://doi.org/10.1080/13658816.2019.1587616

[3] Zhou, Y., Lau, B. P. L., Koh, Z., Yuen, C., & Ng, B. K. K. (2020). Understanding Crowd Behaviors in a Social Event by Passive WiFi Sensing and Data Mining. IEEE internet of things journal, 1-1,. https://doi.org/10.1109/jiot.2020.2972062

PART I: Introduction

Part I

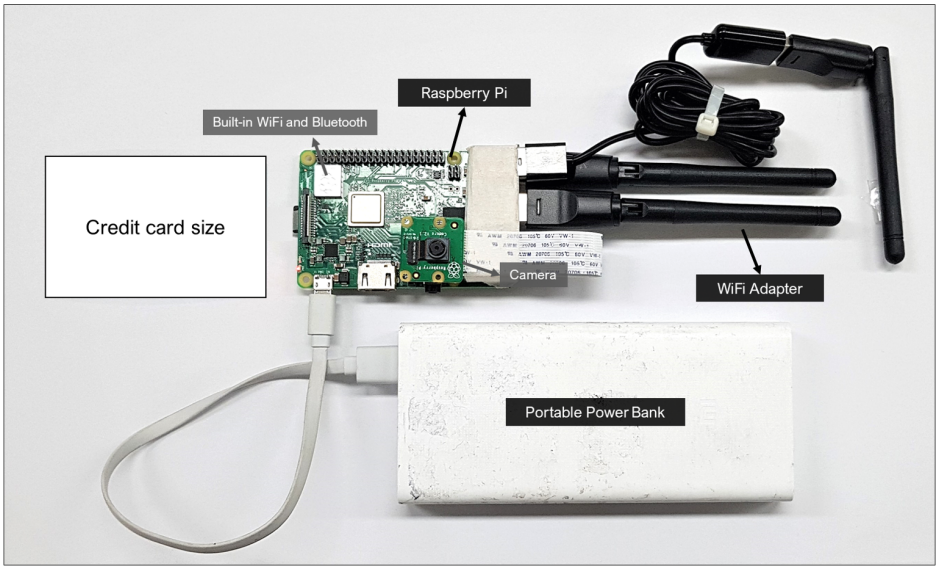
PART II: WiFi Sensing Setup

1 Prerequisites

Before beginning the process of setting up a WiFi sensor, it's essential to ensure you have the necessary hardware *(2.1)*, software *(2.2)*, and skills *(2.3)*.

1.1 Hardware Components

This is the hardware setup illustrating the necessary components required for WiFi sensing:



The required hardware components for this WiFi sensor include:

Hardware	Description	Specific Recommendation
Raspberry Pi board	Core of our sensor	Pi 3B/3B+ or higher
WiFi adapter	Captures WiFi packets	Check chipset compatibility for 'monitoring mode'
Micro SD card and adapter	For system building and data storage	At least 16 GB
Laptop and Ethernet cable	For accessing and controlling the sensor	—
Portable power bank	Powers the sensor in outdoor environments	Battery capacity: +20,000 mAh

Besides these essentials, other hardware components may be attached to the sensor depending on your project requirements, such as:

- **Pi camera:** This can be used to record the scene in front of the sensor.
- **Air pollution sensor:** If you want to monitor air quality in addition to WiFi sensing. Temperature and humidity sensor: Useful for environmental monitoring and adjusting sensor performance based on climatic changes.
- **Temperature and humidity sensor:** Useful for environmental monitoring and adjusting sensor performance based on climatic changes.

1.2 Required Software

The key software programs necessary to build a WiFi sensor and manage the sensor data are:

Software	Purpose	Download Link
Raspberry Pi Imager	Tool for writing Pi OS images onto SD cards	Link
DB Browser for SQLite	Tool for view database written as SQLlite (WiFi packet file type)	Link

Feel free to download these programs in advance. If needed, we will provide the download links again when each step requires these tools.

1.3 Necessary Skills

Basic programming skills, specifically in R and Python, are required. You should be able to write, edit, and debug code. To improve these skills, consider the following courses:

- Data Science: Foundations using R Specialization for a strong foundation in data science using R.
- Python for Everybody Specialization to learn programming basics in Python.

2 Initial Setup

This segment guides you through the complete process of setting up a Raspberry Pi, including the installation of the operating system *(2.1)*, various methods for connecting and accessing your Pi remotely *(2.2, 2.3, 2.4, 2.5)*. Additional troubleshooting and advanced setup tips are also provided in section *(2.6)*.

2.1 Setting Up the Raspberry Pi Operating System

2.1.1 Download the Pi Imager

Begin by downloading the Raspberry Pi Imager, a tool for installing the operating system on your Pi. This software is available on the official Raspberry Pi website. Select the version compatible with your operating system (Windows, macOS, or Ubuntu) and install it on your computer.