Local Positioning System Optimization

by

Astghik Arakelian

Presented to the

College of Science and Engineering

in Partial Fulfillment of the

Requirements for the Degree of Bachelor of Science

American University of Armenia

Yerevan, Armenia

December 2023

Table of Contents

[Introduction 1](#_Toc152437078)

[1.1 Project Description 1](#_Toc152437079)

[1.1.1 Background 1](#_Toc152437080)

[1.1.2 Assumptions and Constraints 4](#_Toc152437081)

[1.2 Overview of the Envisioned System 6](#_Toc152437082)

[1.2.1 Overview 6](#_Toc152437083)

[References 8](#_Toc152437084)

Introduction

## Project Description

### Background

About positioning systems

In this era of automation, the capacity to precisely navigate through various environments predicts the success of the system. The positioning systems (PS) are designed to fit numerous purposes, use cases, and environments and facilitate determining the location and the direction of a system or individuals. Obtaining real-time positioning information is crucial for various instances, including navigation of ships and airplanes, situational management in emergency services, agricultural monitoring, military applications, industrial automation robotics, etc. Different PSs provide varying levels of accuracy and precision based on technology, algorithms, and the environment in which they operate. Most common systems used in smartphones for general purposes have an accuracy of approximately 5 meters [1]. While this accuracy is generally sufficient for everyday use and navigation, some cases, such as autonomous surveillance and navigation, require a more enhanced degree of accuracy. Furthermore, the precision and accuracy rely heavily on the operating environment, to the extent that some PSs might not function efficiently and properly in specific environments. For this reason, different types of PS are used.

Those can be classified into two main categories: global and local positioning systems. Global positioning systems (GPS) utilize satellites to provide worldwide coverage and relatively accurate location information. On the contrary, local positioning systems (LPS) use short-range signaling nodes to obtain the exact location of systems.

Limitations of GPS and about it

GPS operation principle requires continuous signal reception from at least four GPS satellites. The end-receiver determines its distance from the satellites using the time it took for the signals to travel, hence triangulating and obtaining its position. While GPS provides worldwide coverage, its application can be limited to specific environments. Three significant problems can be identified: poor GPS signal reception, loss of GPS signal integrity, and limited positioning precision [2].

Poor GPS signal Reception

As mentioned above, undisturbed signal reception is necessary for the operation of GPS; however, the signals cannot fully penetrate water, walls, bridges, or similar obstacles. This makes GPS less, if not minimally efficient, for cases like underground positioning, navigating by huge obstacles, or in subsurface areas.

Loss of GPS signal integrity

The location is obtained in relation to the satellites from which the system derived its information. This means that incorrect satellite position, distance measurement, or malicious signal manipulation would result in inaccurate positioning. Sometimes, the incorrect signals might not be detected, hence, the system will be unaware of the faulty positioning calculation.

GPS signal accuracy

The signals might also be impacted by their path environment. As the signals pass through the atmosphere, their speed is affected, leading to possible calculation errors [2]. Tr. Similarly, measurement noises or clock errors on the receiver end also affect the calculations [2]. All problems mentioned are critical issues if high accuracy of the positioning is required. Continuous monitoring and signal correction are necessary to reduce the possible errors, but the accuracy would still be limited.

Advantages of LPS

Compared to GPS, LPS can operate in limited geographical areas and, depending on the system specifications, have operation ranges. Technologies and algorithms utilized by LPS are more particular to the operational environment and can be altered accordingly to meet certain needs. These systems can function based on Wi-Fi triangulation, Bluetooth, radio signals’ time-of-flight measurement algorithms, infrared sensors, or a combination of different technologies. The short-range signaling specification of LPS allows to obtain relatively accurate and precise positioning information, enabling systems to alternate their precision based on specific needs (i.e., power consumption, system limitation, use cases, etc.). LPS outperforms global systems in environments where GPS is denied or its accuracy and precision are highly limited.

LPS specification

Compared to various types of LPS, utilizing Software-Defined Radio (SDR) technology gives the advantage of having adaptable and flexible solutions. SDR technology provides software-based algorithms and configurations, allowing it to process diverse signals and operate in different environments and conditions. This advantage enables obtaining better and more accurate positioning information and tailoring algorithms, protocols, and solutions to suit particular applications and needs. Prototyping and testing are relatively more straightforward and less complicated due to their adaptiveness, providing a great environment to improve and upgrade the algorithms without changing the hardware specifications and avoiding additional costs.

Idea explanation

Numerous implementations of LPS based on SDR are used in different industries and tailored to meet the use-case needs. A particular local positioning system has been developed by author1 and author2 to accommodate drones flying and provide surveillance over predefined areas in a sea. This project aims to extend and optimize the implementation of the initial LPS model. The technologies and main algorithms will be reused and optimized based on certain needs that have occurred during the system's operation (e.g., hardware implementation of FFT instead of software). Eventually, this project will be an optimized and improved implementation of the previously developed model (Model0).

### Assumptions and Constraints

SoC resource limitations

In this project, the tools and technological resources utilized are identical to those of Model0. The Model0 heavily depends on system-on-a-chips (SoC) with integrated FPGA, which offers great flexibility and developmental opportunities. However, at the same time, the resources offered by the SoC are limited and require careful consideration. Design trade-offs will happen between the CPU cores and FPGA to increase performance. On Model0, one of the tasks, the Fast Fourier Transform (FFT) algorithm, is implemented on software; however, in this project's scope, FFT will be implemented on FPGA. In terms of available logic elements and hardware blocks, limitations will occur and restrict the complexity of the design. A thorough evaluation will be required to balance the tasks completed on software versus hardware to achieve maximum optimization.

Clock limitation

Furthermore, to improve the precision and responsiveness of the LPS, managing the clock speed is crucial. Clock speed impacts the speed of calculations and data processing. Faster processing will help with quicker analysis of signals and computation of positions, leading to improved real-time accuracy. This is especially useful in dynamic environments where the system is moving. However, the clock speed is limited for the SoC as higher clock frequencies increase power consumption and heat generation [3]. Additionally, because of limited routing resources in FPGA and interconnects between logic elements, high clock speeds might lead to critical propagation delays resulting in timing violations. While designing the FPGA, the balance in the clock speed with resource utilization and routing efficiency is necessary to meet the timing constraints. Moreover, at higher clock frequencies, the quality of signals can be affected by factors such as crosstalk electromagnetic interference. Hence, signal integrity needs to be ensured. Maximum allowable clock speed should be considered regarding thermal constraints, power consumption, design specifications, and signal integrity.

Faster implementation

As already mentioned, the implementation of FFT will be shifted to hardware, designing it on FPGA. Using FPGAs gives the advantage of parallel processing and optimizing the architecture specifically for FFT computations [reference]. The dedicated hardware design will result in lower latency and more efficient resource utilization for the FFT algorithm compared to software solutions running on the CPU. As a result, the implementation designed on FPGA will be notably faster compared to Model0’s solution.

Power saving implementation

However, FPGA can consume significant power, especially if we use programmable logic extensively. The power consumption will significantly increase as the system needs to run multiple tasks. Thus, the balance of power consumption between the FPGA and other components, such as the CPU, should be obtained. Efficient and optimized design with reduced unnecessary logic and well-organized placement can highly affect power consumption. Along with this, proper thermal management might affect power consumption, as current leakages can increase in cases of high temperatures. With these strategies, the optimized performance should also minimize the energy consumption for Model1 compared to Model0. Educated guess processors vs hardwares.

Time constraints

It is essential to acknowledge that achieving the best implementation and final concept may require prolonged development time because of the complexity of FPGA-based implementations. The specialized environment of FPGA programming and hardware design requires a significant upfront investment of time and expertise. While these FPGA-based solutions offer optimized speed and efficiency, their development phase might require more dedicated attention, trials, and expertise compared to software-based approaches. This development phase is the initial proof of concept, demonstrating the feasibility and foundational aspects of the project. However, it's important to note that this is the initial phase. Further work and in-depth development with a more extensive timeframe will be needed past this proof-of-concept stage to achieve the comprehensive final version of the project.

## Overview of the Envisioned System

### Overview

References

|  |  |
| --- | --- |
| [1] | F. van Diggelen and P. Enge, "The World’s first GPS MOOC and Worldwide Laboratory using Smartphones," in *Proceedings of the 28th International Technical Meeting of the Satellite Division of The Institute of Navigation*, Tampa, 2015. |
| [2] | A. Kleusberg and R. B. Langley, "The limitations of GPS," in *GPS World*, 1990. |
| [3] | Xilinx and Inc, "Zynq-7000 SoC (Z-7007S, Z-7012S, Z-7014S, Z-7010, Z-7015, and Z-7020): DC and AC Switching Characteristics Data Sheet," 2011. [Online]. Available: www.xilinx.com. [Accessed 2023]. |