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MULTI-SENSOR FUSION AND GROUND VEHICLE-ASSISTED LOCALIZATION APPROACH FOR UNMANNED AERIAL VEHICLE

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By

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February 2021

Chair : Md Amzari bin Md Zhahir, PhD
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Unmanned aerial vehicles (UAV) has numerous types of applications nowadays. They serve as surveillance units, military support, and rescuing in battlefields. Accurate localization is crucial to enable any high-level intelligent algorithm. Typical localization algorithms for UAVs use sensors data onboard and fuse them. Some models in the literature augmented the sensor data onboard with sensing data generated at a collaborating device outside the subject device. However, this has not been applied to improve the accuracy of the localization using sensor fusion approach for UAV. This study aims at filling this gap by improving the localization performance of the aerial vehicle through augmenting its sensing fusion with sensing data generated at ground vehicle navigating in the angle of view of the UAV. Two Multi-Sensor Kalman filter will be used for this purpose, one for the position and one for attitude. Accelerometer, gyro, compass, camera located on the UAV are used, while the encoder and compass are used in the ground vehicle, on the other side an outside camera is positioned to play the role of GPS in an outdoor environment. All the data are fused using geometrical transformation to project them into the same space. Comparison with single sensor Kalman filter and based on various trajectories scenarios show the superiority of Multi-Sensor Kalman filter for better accuracy and less mean square error MSE of trajectory. A mean square error of our developed Multi-Sensor Kalman filter has been to be 0.005 for x, y and z coordinates comparing with 0.026 in the benchmark. Similarly, an outperformance in the attitude was observed with an MSE of 2.396e-05 comparing with 8.11e-4 for the benchmark. This developed collaborative multi-sensor Kalman filter for UAVs localization can be used as an improving option for multi-vehicles applications.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk untuk ijazah Master Sains

PENDEKATAN LOKALISASI BANTUAN PELAKURAN PENDERIA BERBILANG DAN KENDERAAN DARAT UNTUK PESAWAT TANPA PEMANDU

Oleh

ABDELRAZIG SHARIF SAYED MOHAMED

Februari 2021

Pengerusi : Md Amzari bin Md Zhahir, PhD
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Pesawat tanpa pemandu (UAV) mempunyai pelbagai jenis aplikasi pada masa kini. UAV berkhidmat sebagai unit pemantauan, sokongan ketenteraan, dan penyelamat dalam medan pertempuran. Penyetempatan yang tepat penting untuk membolehkan algoritma kecerdasan aras tinggi. Algoritma penyetempatan lazim untuk UAVs menggunakan data penderia atas papan dan lakurkan mereka. Sesetengah model di dalam sorotan kajian mengimbuh penderia atas papan dengan data penderiaan yang dijana pada peranti berkolaborasi di luar peranti subjek. Namun, ini belum diterapkan untuk meningkatkan ketepatan penyetempatan menggunakan pendekatan pelakuran penderia untuk UAV. Kajian ini bertujuan untuk mengisi jurang ini dengan meningkatkan prestasi penyetempatan kenderaan udara melalui pengimbuhan data lakuran dengan data penderiaan yang dijana pada kenderaan darat yang memandu arah sudut tinjauan UAV. Dua penderia berbilang turas Kalman digunakan untuk tujuan ini, satu untuk kedudukan dan satu untuk attitud. Akselerometer, giro, kompas, kamera yang diletakkan dalam UAV digunakan, manakala pengekod dan kompas digunakan dalam kenderaan darat, pada bahagian lain satu kamera luar diletakkan untuk memainkan peranan GPS di persekitaran luar. Kesemua data yang dilakurkan menggunakan penjelmaan geometri untuk mengunjurkan mereka ke ruang sama. Perbandingan dengan turas Kalman penderia tunggal dan berdasarkan pelbagai senario trajektori menunjukkan keunggulan turas Kalman berbilang penderia untuk memberikan ketepatan yang lebih baik dan ralat min kuasa dua terkecil (MSE) trajektori. Ralat segi empat sama bagi turas Kalman berbilang penderia yang dibangunkan ialah 0.005 untuk koordinat x, y dan z berbanding dengan 0.026 sebagai penanda aras. Begitu juga, prestasi yang lebih baik dalam atitud diperhatikan dengan MSE 2.396e-05 dibandingkan dengan 8.11e-4 sebagai penanda aras. Turas Kalman berbilang penderia kolaboratif yang dikembangkan ini untuk penyetempatan UAV dapat digunakan sebagai pilihan peningkatan untuk aplikasi berbilang kenderaan.

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My hope is that anyone who encounters and gains knowledge from my work will remember me in his/her supplications (do'a).

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LIST OF ABBREVIATIONS

AHRS	Attitude and Heading Reference Systems
AI	Artificial Intelligence
IMU	Inertial Measurement Unit
INS	Inertial Navigation Systems
KF	Kalman Filter
MS-KF	Multi-Sensor Kalman Filter
SS-KF	Single Sensor Kalman Filter
UAV	Unmanned Aerial Vehicle
UAV-CLS	UAV-Collaborative Localization System
UGV	Unmanned Ground Vehicle

CHAPTER 1

INTRODUCTION

1.1 Introduction

Recently, robotics technology has emerged, and many new applications are created religiously. Robotics include numerous types of environments where the robots are expected to operate, ground, aerial, under-water, space, other planets and the human body. The extraordinary developing of robotics applications relies on two elements: the first one is the impressive development of artificial intelligence, AI, especially in the last decade which has made it possible to imitate various intelligent aspects in nature and creatures in an algorithmic way (Nayar, 2015). The second element is the hardware development that enabled implementing sensing technology of different signals in the world. Looking at robots as artificially intelligent entities requires providing the needed amount of perception in one side and enabling the actuation capability on the other side. In the middle between perception and actuation, intelligent algorithms operate to close the loop that generates a robot capable of performing specific tasks finally. Without perception, actuation will have no usefulness, and without actuation perception also will have no usefulness. Figure 1 provides a conceptual diagram of the relation between perception and actuation in robotics systems.

One of the primary information that needs to be perceived in order to enable a proper actuation to robots is the location. The layer that deals with sensors data and provides perceptual results is where localization belongs. In order to improve localization, the gathering of data from multi-sensors and smartly fusing them is essential. Localization is defined as estimating the position and attitude of the moving object. Two-dimensional localization is more applicable in environments where only ground robots are used; however, the most general localization is three-dimensional, which is common in aerial and underwater vehicles.

Assisted localization between multi-vehicle is one key aspect of robust localization. In many applications, aerial vehicles when they are deployed to do specific tasks collaborate with ground vehicles, for example, rescuing soldiers at battlefields or exploring unknown environments (Beck, Teacy, Rogers, & Jennings, 2016). Exploiting the collaborative nature of the application, we can enhance location estimation of the aerial vehicle using assisting data from a ground vehicle located in its angle of view.

The goal of the thesis is to develop a novel multi-sensor Kalman filter-based approach to demonstrate the effectiveness of aerial-ground vehicle collaboration for improving the localization of aerial vehicle. The two-dimensional nature of the ground vehicle adds more stability to its sensing data, and the broad view of the aerial vehicle vision adds a more comprehensive sensing nature. Integrating both of them in one sensing and localization platform has a high potential for improving the localization of unmanned aerial vehicle.

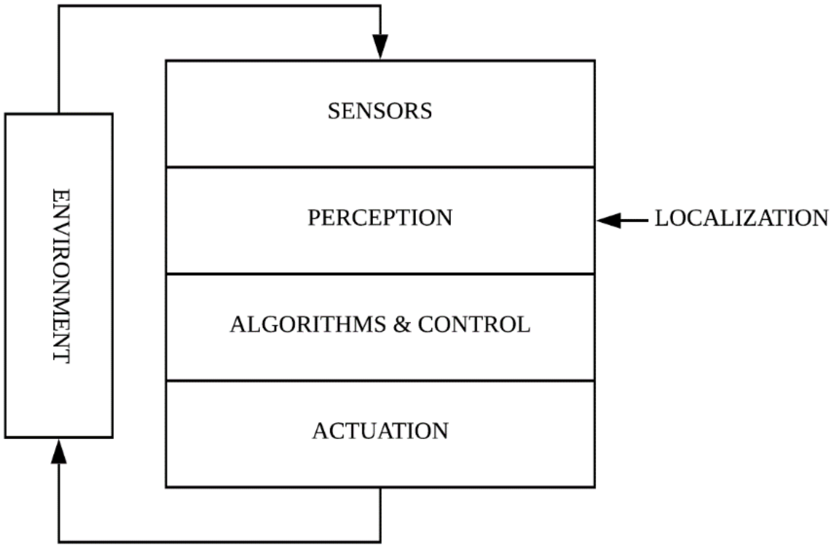

Figure 1: Conceptual diagram of the relation between perception and activation in robotics

1.2 Motivation

The localization of unmanned aerial vehicles UAVs in the indoor environment has a wide range of applications. We state in this section, some of them in order to motivate the reader about the study.

a. Rescuing:

Aerial vehicles able to cover a wide area in rescue missions has increased the rate of gathering information about survivals and injured, relatively (Naidoo, Stopforth, & Bright, 2011), (Naidoo et al., 2011); making aerial vehicles central to the search task. Not to mention the reduced risk to humans involved in the search and rescue mission, their advantage over helicopters that allow them to be deployed from anywhere rather than a base.

b. Surveillance:

Starting with the use of UAVs in military applications until a recent significant drift into civilian domains, UAVs have always been used in surveillance (Acm, Semsch, & Jakob, 2009). Aerial vehicles are used in surveillance to gather information about areas solely or collaboratively. The surveillance problem has significantly improved over the years in cluttered and occluded environments due to advancements in the collaborative nature of the mission and the improved localization of the aerial vehicles (Ma'Sum et al., 2013).

c. The Assistance of Older People:

Continuous testing is burdensome to ageing people and their caregivers, regardless of its significant necessity, as well as medication supplies and replenishments. Ganchev, Garcia, Dobre, Mavromoustakis, & Goleva, 2019 has proposed the use of drones in delivering medications and transporting samples, for instance, blood, to the hospital. Aerial vehicles can also be used to have the doctor remotely check on the patient and receive immediate notifications in case of emergencies.

1.3 Problem Statement

Reading the previous works in the literature about the localization of unmanned aerial vehicles, we observe that researchers have faced the issue of non-capability of one sensor to handle the position estimation by itself. Instead, the philosophy of multi-sensor fusion is preferred, providing that the estimation error that occurs from multi-sensor is at least equal or lower than the estimation error of a single sensor. Researchers have used the Kalman filter framework for handling multi-sensor fusion of aerial vehicles. However, most of them have relied only on sensor data generated in the aerial vehicle itself. To the best of our knowledge, none of them has tackled the problem of aerial vehicle localization using the fusion of data generated at the aerial vehicle as well as another moving ground vehicle in the scene of the camera located inside the aerial vehicle. Exploiting the fact that the ground vehicle has more perceivable trajectory as it moves only in two dimensions and its data can be transmitted to the aerial vehicle in various applications, (example: friend-friend collaboration in the battlefield), we claim that improving the localization algorithm of aerial vehicle has high potential in the case of adopting the view of fusing the data generated from both the aerial and ground vehicle.

1.4 Objectives

The goal of this study is to propose and implement an assisted localization algorithm of unmanned aerial vehicle using data provided from ground vehicle. The goal is reached based on the following objectives:

1. Developing Multi-Sensor fusion model of aerial and ground vehicle data using multi-sensor Kalman filter we name it as Unmanned Aerial Vehicle Collaborative Localization System UAV-CLS.

2. Evaluating the proposed UAV-CLS and compare it with a baseline approach that uses only sensor data of the unmanned aerial vehicle. MATLAB and Simulink simulation and standard evaluation measures will be used for implementing this objective.

1.5 Scope

We assume that the unmanned aerial vehicle is moving within a trajectory where it is capable of observing the ground vehicle inside its camera view angle. Also, we assume that the ground vehicle sends its sensor data to the aerial vehicle using certain communication protocol like Zigbee. The study will not address the details of the communication. The focus is on the algorithm of localization considering that data were already transmitted properly. Regardless of the different frame-rates of the sensors, our multi-sensor fusion operates under fixed framerate. The study is applicable to both tele-operated and autonomous.

1.6 The Outlines of the Thesis

The rest of the thesis is organized as follows.

Chapter 2 provides a comprehensive literature survey of the different localization algorithms developed for unmanned aerial vehicles. Furthermore, a presentation of Kalman filter and its various variants is provided.

Chapter 3 provides our developed methodology for implementing UAV-CLS using MS-KF and the baseline approach for comparison using SS-KF.

Chapter 4 gives the testing scenarios, simulation parameters, generated results, and the needed analysis of performance.

Chapter 5 gives the summary and conclusion of the study, contributions, findings, limitation, and the future works.

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