# Review of the Doctoral Dissertation

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| Title of the dissertation: | **Tracking Head Movements in a Flight Simulator Environment using SLAM Mechanism of Augmented Reality Goggles** |
| Author: | **MSc Onyeka Josephine NWOBODO** |
| Supervisor: | **Dr hab. Eng. Krzysztof Adam CYRAN, Prof. Silesian University of Technology** |
| Field: | **Technical Sciences** |
| Discipline: | **Information and Communication Technology** |

## 1. Assessment of the Structure of the Dissertation

The dissertation under review is extensive, comprising 238 pages of text divided into 10 main chapters. It also includes a table of contents, a list of figures, a list of abbreviations, and a bibliography.

Chapter One outlines the main issues related to the use of flight simulators in pilot training. Attention is drawn to the potential of augmented reality technologies to improve pilot training effectiveness and to the challenges in designing such solutions. According to the author, a critical element is tracking the trainee's head position within the simulator environment. This process must feature minimal latency and deliver reliable, real-time positional data in the simulator's dynamic environment to ensure situational awareness, sound decision-making, and effective training.

Chapter Two presents a literature review related to the discussed problem. Particular attention is given to existing marker-based head-tracking technologies and navigation solutions that use SLAM algorithms to track the pilot's head in flight simulators. The main conclusion from this review is that smooth, responsive, and reliable head tracking can be achieved by developing an advanced algorithm that addresses latency, drift, and fluctuations.

Chapter Three focuses on the analysis of various SLAM algorithm variants for head movement tracking during exercises in a flight simulator with augmented reality. The research identifies strengths and limitations—relevant from an AR perspective—of the following algorithms: RGB-D SLAM, ORB SLAM, LSD SLAM, Visual-Inertial SLAM, and deep-learning-based SLAM.

Regardless of the tracking method, a key challenge for AR is ensuring precise alignment of virtual elements with physical cockpit components. Chapter Four discusses these issues and compares marker-based approaches with SLAM algorithms. A key conclusion is the recommendation to design a hybrid solution that integrates the precision of marker-based tracking with the flexibility and scalability of SLAM.

Chapter Five considers the usability of AR interfaces in a cockpit simulator. The research uses Fitts' Law to evaluate pointing tasks in human–computer interaction. A test setup based on Microsoft HoloLens 2 was developed. The results provide design guidelines for reducing task difficulty, optimizing object placement, and improving interaction.

Chapter Six describes the framework of a hybrid adaptive filter combining Kalman and particle filters, which adjusts filtering for linear dynamics (Kalman filter) and nonlinear dynamics (particle filter). Three Kalman filters, three particle filters, and hybrid pairs were independently tested for the fidelity of head movement tracking in an AR flight simulator environment, aiming for low latency, acceptable computational demand, and high accuracy and responsiveness.

The Microsoft HoloLens 2 device used in the experiments enables simultaneous acquisition of eye-tracking, head-tracking, and hand-gesture data. Chapter Seven presents a method for identifying the pilot using these data via a multi-branch Long Short-Term Memory (LSTM) neural network. The method was evaluated and yielded promising results. Although not strictly aligned with the dissertation topic, this solution enhances usability by removing the need for login and environment reconfiguration when trainees change.

Chapter Eight investigates training effectiveness in an AR-based flight simulator. A non-invasive method is proposed to estimate the amount of information retained by trainees. This type of assessment helps create adaptive, lightweight, and measurable training environments. Although not strictly related to the dissertation topic, it contributes to the design of safe, effective, and personalized training settings.

The augmented reality framework described in this work for flight simulators, with solutions that guarantee high fidelity and training effectiveness, has features that can be used in other environments. Chapter Nine demonstrates the applicability of the developed AR framework for presenting topics in quantum mechanics, confirming that the proposed solution may be useful beyond flight simulation contexts.

Five essential chapters of the dissertation were based on co-authored publications in which the PhD candidate was a co-author. These are:

- Chapter 3 – publication no. [16] - the chapter title and article title are the same
- Chapter 4 – publication no. [37] - the chapter title and article title are the same
- Chapter 5 – publication no. [178] - the chapter title and article title are the same
- Chapter 6 – publication no. [197] - the chapter title is very similar to the article title
- Chapter 8 – publication no. [276] - the chapter title and article title are the same

The bibliography contains 320 items—sufficiently broad and effectively positioning the research within international works. The literature listed for those chapters corresponds to the literature cited in the related articles.

## 2. Aim and Scope of the Dissertation

The goal of the dissertation was to develop solutions to improve pilot training effectiveness in flight simulators, ensure realistic perception across complex scenarios, and ensure reliable operation. The candidate chose to employ augmented reality based on Microsoft HoloLens 2. This approach required designing a method for precise head-position tracking inside the cockpit with minimal latency and positional error, while keeping computational cost low.

The candidate analyzed and evaluated a range of tracking methods using markers, IMUs, and SLAM variants. The primary outcome is a novel adaptive hybrid solution integrating marker-based tracking with selected SLAM algorithms. Filtration significantly enhanced the solution's quality. Multiple variants of Kalman and particle filters were tested, and an adaptive hybrid variant was incorporated into the final approach.

The research extended beyond this primary goal. Using AR-derived data, the candidate proposed a method for identifying pilots based on behavioural analysis, supporting modern flight simulator environments.

Another added value is the capability to assess training effectiveness, enabling informed shaping of training scenarios and influencing future simulator design to reduce interaction difficulty for trainees.

## Assessment of Research Methods

The dissertation examines several independent groups of solutions: marker-based tracking, SLAM-based tracking, particle-filtering methods, Kalman-filtering methods, and neural-network-based methods. These topics span Chapters Three to Nine.

Across all investigations, the methodology followed a similar structure: detailed description of the problem and algorithm, preparation of a dedicated experimental setup, execution of experiments, illustration and multidimensional presentation of results, and concise conclusions with usage recommendations.

This approach effectively combines theoretical and experimental research, and the results appear highly credible.

## Assessment of Practical Applications

The topics are presented clearly and supported by figures that enhance the quality. A significant drawback is that figures often appear several pages after their first reference, making analysis difficult.

The dissertation focuses on the practical use of the developed methods in modern flight simulators. Applications in other domains, including medicine, are frequently noted. Chapter Nine demonstrates the practical use of the AR framework in teaching quantum mechanics concepts.

The proposed solutions will undoubtedly find practical applications.

## Originality of the Scientific Contribution

The proposed solution:

- uses augmented reality;
- employs an adaptive hybrid tracking approach integrating markers and selected SLAM algorithms;
- improves data quality through adaptive Kalman and particle filtering;
- enables identification of trainees based on eye, head, and hand-gesture tracking;
- provides potential for assessing knowledge retention and influencing training scenario design.

This approach is original and constitutes a significant contribution to the development of modern flight simulators. The hybrid adaptive tracking solutions may also apply to navigation and drone and swarm management systems.

## Assessment of Theoretical Knowledge and Independent Research Skills

Each chapter from Three to Nine contains a methodology section. These sections demonstrate the candidate's advanced theoretical knowledge relevant to the discipline and each topic. The candidate uses mathematical tools fluently, as evidenced by the experiment-related subsections that present results and analyses.

The literature review shows strong familiarity with the discipline of Information and Communication Technology. Seven co-authored publications from 2023 to 2025 in international peer-reviewed conferences and journals are listed.

## 3. Weaknesses of the Dissertation

### General

1. The dissertation was reviewed as a "written work," not a "collection of published and thematically related scientific articles" (as defined in the Law on Higher Education). However, five chapters share nearly identical titles with multi-author publications and contain similar content, including reused figures with no references to the original publications. It is unclear whether the candidate obtained permission to reuse those figures.
2. The dissertation does not specify the candidate's contribution to those publications. Such information should be presented at a minimum during the public defence.
3. There are symptoms of the use of artificial intelligence in preparing the text—which is not inappropriate—but the candidate should state which parts were prepared using which tools.

### Structure and Content

4. Repetitions occur throughout the dissertation, making it difficult to follow and forcing the reader to re-read sections unnecessarily. Examples include:
   - The first paragraph on page 56,
   - The first paragraph of Section 6.1.1,
   - The last paragraph of Section 6.1.2.
5. Although a glossary is provided, full term descriptions with abbreviations are unnecessarily repeated (e.g., "augmented reality (AR)").
6. Several issues with figures and references are noted, such as figure placements several pages away from their references.
7. A significant shortcoming that hinders comprehension is the distance of several pages between the reference to a Figure and its location. Here are a few examples:
   - The reference to Figure 4.3 is on page 59, and the figure is on page 61.
   - The reference to Figure 4.4 is on page 60, and the figure is on page 62.
   - References to Figures 5.12 and 5.13 are on page 86, and the figures are on pages 101 and 102, respectively.
   - The reference to Table 5.4 is on pages 91, 94, and 95, and the table is on page 95.

   Similar comments apply to figures 5.2, 5.3, 5.7, 5.8, and 5.15.

   For this reason, chapter five is difficult to understand and gives the impression that it was written by someone other than the author of the other chapters.

8. Other issues include the use of overly sophisticated vocabulary that complicates understanding, e.g.:
   - p. 114 – "intricately" instead of "carefully"
   - p. 131 – "exacerbate" instead of "increase"
   - p. 181 – "insurmountable" instead of "unbeatable".

### Editing Issues

The list of editorial inconsistencies includes duplicated paragraphs, incorrect references, missing identifiers, unclear formulas, unreadable figures, incorrect sequencing, and inconsistencies in notation. They are as follows:

- page 41 – there are two large paragraphs with almost identical content.
- page 50 – there is a reference to 'Figure 1', but there is no such figure in the paper. There is a figure marked Figure 3.1. However, in article [16], on which chapter three is based, there is an identical figure marked 'Figure 1'.
- page 51 – a similar comment applies to references to 'Table 1', 'Table 3.1' and article [16].
- page 63 – there is a reference to formula '3.2', but it should probably be formula 4.2.
- pages 81 and 83 – the formulas do not have their own identifiers.
- page 84 – there are incorrect letters in the chapter title.
- page 94 – formula (5.5) contains the abbreviation 'AVG', which is not explained anywhere.
- page 95 – there is a reference to 'Figure 5.10', but it is not clear what it illustrates.
- page 109 – the phrase 'We' is used in many places in the work. This raises doubts as to whether the work was done independently.
- page 110 – there is a reference to 'Algorithm 1', but it probably refers to 'Algorithm 2'.
- page 113 – formula (6.4) contains the element $P^{-}_{k}$, which is not described.
- page 114 – formula (6.7) contains the element $a_{k-1}$, which is not described.
- page 130 – there is a reference to 'Table I in the appendix' – there is no 'Table I' or 'Appendix' in the work.
- page 150 – 'Figure 7.1' is practically illegible.
- page 153 – there is a reference to 'Figure 2', but this probably refers to 'Figure 7.2'.
- page 165 – there is a reference to section V-A, which does not appear in the work.
- page 181 – the word 'Broglie's' is used twice.
- page 187 – the order of 'Figure 9.5' and 'Figure 9.6' should be reversed.

## 4. Summary Assessment

Despite the listed shortcomings, the dissertation meets the requirements for doctoral theses thanks to its strong substantive quality and significant implementation potential.

**The dissertation is evaluated positively.**

## Conclusion

I consider the dissertation an original solution to a scientific problem, demonstrating the candidate's theoretical and practical knowledge in Information and Communication Technology, as well as her ability to conduct independent scientific research.

Based on the above assessment, **I confirm that the dissertation meets the requirements defined by the Law on Higher Education (Act of 20 July 2018)** and **recommend that MSc Onyeka Nwobodo be admitted to the public defense of the doctoral dissertation.**