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Doctoral dissertation review

The review of the doctoral dissertation of Onyeka Josephine Nwobodo entitled "*Tracking Head Movements in a Flight Simulator Environment using SLAM Mechanism of Augmented Reality Googles*" was prepared at the request of the Chairman of the Technical Informatics and Telecommunications Discipline Council of the Silesian University of Technology.

1a) Subject matter of the dissertation and title of the thesis

The subject of the doctoral dissertation of Onyeka Josephine Nwobodo, MSc, Eng., entitled "*Tracking Head Movements in a Flight Simulator Environment using SLAM Mechanism of Augmented Reality Googles*" concerns the issue of tracking head movements in a flight simulator environment using the SLAM mechanism, i.e. simultaneous locating and mapping.

The dissertation concerns the development and validation of an innovative head tracking system for AR flight simulators, based on SLAM technology and adaptive fusion of Kalman and particle filters, in order to increase the accuracy, stability and responsiveness of tracking in the cockpit environment. The work includes the analysis and comparison of existing tracking methods (marker and inertial) with the SLAM approach, extended by the layer of user identification and memory retention prediction using LSTM models, which enables personalization and adaptive control of the training process.
In my opinion, the subject of the thesis was described correctly.

1b) Characteristics of the trial and assessment of the layout of the hearing

The doctoral dissertation of Onyeka Josephine Nwobodo entitled "*Tracking Head Movements in a Flight Simulator Environment using SLAM Machanism of Augmented Reality Googles*" consists of a total of ten chapters, including: introduction, main part of the thesis, summary and bibliography. The entire work takes up over 220 pages with a bibliography and appendices.

The first chapter introduces the issues of the work, presenting the background of the development of flight simulation technology and the growing role of augmented reality in pilot training. A research gap regarding the inaccuracy and instability of head tracking systems is defined, research questions and dissertation objectives are formulated, and the adopted methodology is described in detail, including literature review, implementation of SLAM algorithms, comparative analyses, development of adaptive filter fusion, deep learning models, and validation procedures and statistical analysis. The scientific and application significance of the research is also indicated and the hardware architecture of the AR goggles used in the experiments is characterized.

The second chapter provides a systematic review of head tracking methods in AR systems, including solutions based on optical, magnetic, acoustic and inertial sensors, as well as machine learning approaches. Degrees of head freedom of movement (DoF), technological constraints and current development directions were analysed, identifying key challenges such as drift, obscuration and vulnerability to environmental disturbances.

The third chapter focuses on SLAM methods in the context of AR flight simulators. Selected algorithms, including RGB-D SLAM, ORB-SLAM, LSD-SLAM, VINS, and deep learning-based approaches, are presented and compared, describing their implementation, experimental configuration, and analysis of the results in terms of mapping accuracy, trajectory stability, and suitability in the cockpit environment.

Chapter four provides a detailed comparative analysis of marker and SLAM-based tracking in AR flight simulation. Camera calibration procedures, data processing flows, evaluation metrics, and quantitative results are described, taking into account the impact of sensor resolution and marker size on detection range. The SLAM approach has demonstrated the advantage of adaptability, resilience to disruption and immersiveness.

Chapter five presents the adaptation of Fitts's law to three-dimensional AR environments. A modified model was developed to take into account head orientation, spatial anchorage of objects and environmental factors, and then experiments were conducted with statistical analysis of the impact of target location, lighting and stage complexity on the difficulty of the task. The results were used to optimize the placement of interface elements in the AR cockpit.

Chapter Six describes the development of adaptive fusion of Kalman and Molecular Filters (AKPF) for high-precision head tracking. Extended versions of EKF, UKF, ENKF, and particle filters (SIR, APF), including GPU-accelerated implementations, are shown, and then their performance in terms of RMSE, trajectory stability, latency, and compute workload is compared. The analysis demonstrated the superiority of adaptive fusion under conditions of nonlinear motion dynamics.

Chapter seven deals with user identification in AR based on multimodal behavioral data. An LSTM architecture was designed to model temporal patterns of head movements, gaze and hand gestures, and the effectiveness of the system was assessed using measures such as *accuracy, precision, recall, balanced accuracy* and the t-SNE error matrix and visualization. An analysis of generalizations to new users and comparison with reference methods was also performed.

Chapter eight introduces a deep learning model to predict memory retention in an AR environment. Based on non-invasive behavioral indicators, a DNN network was developed to predict memory status, enabling adaptive learning rates and personalization of cognitive support. The results of the experiments confirm the accuracy of the prediction and the statistical significance of the effects obtained.

Chapter nine presents a case study of the use of the developed AR architecture in STEM education on the example of the visualization of the Mach–Zehnder interferometer. The design of the immersive environment, experimental procedures and comparative analysis of the effectiveness of learning in relation to traditional methods are described, demonstrating an improvement in the understanding of abstract concepts of quantum mechanics.

Chapter ten summarizes the results of the research, synthesizes the theoretical and application contributions of the dissertation, and indicates directions for further work, including the development of high-precision AR systems for tracking in aviation, UAV systems, and other fields requiring advanced spatial mapping and adaptive human-system interaction.

The author uses the correct terminology in the field of the subject of the work

The titles and order of the chapters is also correct, the content of the chapters corresponds, in my opinion, to the requirements set for doctoral theses.

1c) Assessment of the literature used

The bibliography consists of 320 items related to the subject of the work. The literature items have been selected correctly, taking into account their relevance and topicality. They were correctly incorporated into the content of the dissertation.

1d) indication and assessment of the purpose of the work

The aim of the work is to develop and validate an innovative head tracking system for AR flight simulators, based on SLAM technology and adaptive fusion of Kalman and particle filters, in order to increase the accuracy, stability and responsiveness of tracking the pilot's reaction in the cockpit environment. Another goal is to overcome the limitations of existing marker and inertial methods by analyzing, optimizing, and comparative evaluating different SLAM algorithms in realistic flight scenarios. The next goal is to develop a layer of intelligent personalization that includes user identification based on multimodal behavioral data and prediction of memory retention using deep learning models. The work also aims to reduce delays, tracking errors and simulation sickness, thereby increasing the immersion and efficiency of pilot training. An additional objective is to create a general methodological and design framework that can be applied not only in aviation, but also in other fields that require precise spatial mapping and adaptive human-system interaction.

In my opinion, the objectives of the work were achieved in the correct way.

1e) indication and evaluation of the test methods used,

The paper uses an integrated research approach combining literature analysis, systems design, laboratory experiments, and advanced statistical analysis and algorithmic modeling. In the first stage, a systematic review of existing AR head tracking methods, including marker, inertial and non-marker techniques, was carried out, which allowed to identify technological limitations and formulate design assumptions for a SLAM-based system. Next, selected SLAM algorithms (m.in. ORB-SLAM, RGB-D SLAM, VINS) were implemented and tested, analyzing their mapping accuracy, trajectory stability, and resistance to interference in the flight simulator cockpit environment.
A key research method was an experimental comparative evaluation of marker tracking and SLAM systems, including camera calibration, data flow analysis, and measurement of quantitative metrics such as mean square error (RMSE), system latency, position and orientation stability, and resistance to obscuration. Various filtration techniques were used and compared for condition estimation, including extended Kalman filter (EKF), odorless filter (UKF), combination filter (EnKF) and particle filters (SIR, APF), and then an adaptive method for fusion of Kalman and molecular filters (AKPF), verified under dynamic and nonlinear conditions, was developed.
In the area of human-system interaction, user experiments and mathematical modeling based on Fitts's modified law for three-dimensional AR environments were used, taking into account the orientation of the head and spatial anchoring of objects. Statistical methods were used to analyze the data, including significance tests, analysis of variance, and multivariate evaluation of interaction performance.

The AI section uses deep learning methods, in particular multimodal LSTM networks to identify the user based on temporal sequences of head movements, glances and hand gestures, assessed using measures such as *accuracy, precision, recall, F1-score and balanced accuracy.* In addition, a DNN-based memory retention prediction model was developed, trained on non-invasive behavioral data, the effectiveness of which was verified experimentally and statistically. The entire research was empirical and algorithmic, combining the implementation of the system in the AR environment with quantitative validation and comparative analysis.
I believe that the research methods have been applied in the correct way.

1f) evaluation of the part of the doctoral dissertation concerning the discussion of research results

The results of the study confirmed a statistically significant improvement in the accuracy and stability of head tracking thanks to the use of a SLAM-based approach and adaptive fusion of Kalman and particle filters, which translated into a reduction in RMSE error and system latency. Comparative analysis showed the superiority of SLAM methods over marker techniques in terms of resistance to obstruction, drift and changing cockpit environmental conditions. Deep learning models have achieved high efficiency in user identification and prediction of memory retention, confirming the ability to personalize the training process in an adaptive way. The overall assessment indicates that the proposed architecture significantly increases immersion, user comfort and pilot training efficiency, while maintaining real-time computational feasibility.
In my opinion, the substantive work was carried out and described correctly. The author described the methods in detail, in many cases they were illustrated with the help of figures and tables.

1g) **information on the practical application of the test results obtained**

The developed system based on SLAM and adaptive filter fusion can be integrated into commercial and military training platforms, increasing the realism of cockpit mapping, reducing simulation sickness, and improving the efficiency of long-term training sessions. The user identification and memory retention prediction layer enables the implementation of personalized, adaptive training scenarios, automatic difficulty adjustment, and continuous authentication without interrupting the learning process, which is important in environments with increased security requirements.

The application potential extends beyond manned aviation and includes training of unmanned aerial vehicles (UAVs), air traffic management, military simulations, and decision support systems in environments of high operational complexity. The solution can also be implemented in medicine (treatment simulators), industry (service and installation training) and STEM education, where precise spatial mapping and interaction with 3D objects are required. Fitts's adaptation of Fitts's law to AR environments provides practical design guidelines for spatial interface ergonomics, which can be used by AR system manufacturers and software developers. The scalability of the architecture, compatibility with HMD devices and the ability to work in real time indicate a fairly high level of technological readiness of the solution and its real implementation potential

1h) **information on any irregularities that appeared in the evaluated doctoral dissertation,**

No serious irregularities in the trial were identified.

1i) **assessment of whether the doctoral dissertation constitutes an original solution to a scientific problem**

The work is a solution to an original scientific problem of ensuring high precision, stability and adaptability of head tracking in augmented reality-based flight simulation environments. The originality of the dissertation is manifested in the integration of SLAM technology with the proprietary, adaptive method of fusion of Kalman and particle filters, which allowed to effectively solve the problem of nonlinear dynamics and measurement disturbances in real time. Another novel contribution is the combination of high-fidelity spatial mapping with a layer of intelligent user identification and memory retention prediction in a single, consistent AR system. The proposed approach extends existing marker and inertial solutions, offering experimentally established improvements in the accuracy, immersiveness and ergonomics of interactions.
Taking into account all the components, I believe that the dissertation under review contains an original solution to a scientific problem.

1j) **assessment of whether the doctoral dissertation presents the candidate's general theoretical knowledge in the discipline or disciplines and the ability to independently conduct scientific or artistic work,**

In my opinion, the thesis fits into the discipline of technical informatics and telecommunications and is written correctly from the point of view of methodology. The author has demonstrated both theoretical knowledge and practical skills in data analysis and algorithmic development.

Below are comments and questions regarding the substantive side of the work:

1. The author is asked to address the issue of computational scalability and the problem of real-time regime preservation. How can a further reduction in the computational complexity of SLAM algorithms be implemented in practice?
2. How can resistance to stress conditions and so-called sensory degradation be further improved? In particular, the stability of the system in situations of strong vibrations, changing lighting, partial obstruction of the field of view or temporary loss of sensor data.
3. Please address the potential development of user identification layer validation and memory retention prediction procedures on larger, more diverse populations to confirm the resilience of the models to overfitting and ensure their transferability between scenarios.
4. The author is asked to address the problem of standardizing metrics for the evaluation of immersion and potential simulation disease. What indicators correlating technical parameters with subjective user feelings would allow for unambiguous quantification of ergonomic effects?
5. In the author's opinion, how should the next phases of work proceed, i.e. . interoperability with commercial and military simulation platforms, including standardization of APIs, compatibility with communication protocols and analysis of the cyber security of the system?
6. In the concluding chapter, I missed a summary of the contribution to the discipline of Technical Informatics and Telecommunications. That is, from my point of view, there is a lack of a specific list of the most important, detailed achievements of the work from the point of view of technical informatics.

Final conclusion

The dissertation is an original solution to a scientific problem and indicates a high level of theoretical and practical knowledge of the Candidate in the scientific discipline of Technical Informatics and Telecommunications.

The presented doctoral thesis fully meets the conditions set out in Article 187 of the Act of 20 July 2018. Law on Higher Education and Science (Journal of Laws of 2020, item 85, as amended). In particular, in accordance with the requirements of the above-mentioned Act, the evaluated dissertation positively presents the Candidate's theoretical knowledge and ability to conduct scientific work independently, the subject of the dissertation is an original solution to a scientific problem. In the reviewer's opinion, the work may therefore be admitted to public defense.

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