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Using the Digital-Twin Technology in the Mi-17 Mixed Reality Simulator

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Abstract: The article is aimed at the issue of combining the real world with the virtual world in Mixed Reality (MR) simulators. Mixed reality allows for integrating the real world with the virtual world – real objects with computer-generated objects. A person interacting with such a system receives both visual and tactile sensations. To ensure proper interaction with system elements, high reconstruction accuracy of virtual objects in relation to the corresponding real objects is necessary. The article presents the concept of combining the real and virtual world using a combination of VR and digital-twin technology and aims to illustrate how to ensure high accuracy of mapping virtual objects in relation to their real originals on the example of the Mi-17 helicopter simulator made using MR technology.

Keywords: Mixed Reality (MR), Virtual Reality (VR), Mi-17 helicopter simulator, Unity 3D, Digital Twins

1. Introduction

The article is focused on combining the real world with the virtual world in a mixed-reality simulator. Mixed Reality (MR) enables the integration of real world with the virtual world - real world objects with computer-generated objects. A person interacting with such a system receives both visual and tactile sensations. Thus, to ensure proper human interaction with such systems, high precision and reconstruction of shapes and location of virtual objects in relation to their real-world counterparts is needed.

By selecting how to combine the real world with the virtual one in a given application, we must know where it is located on a Reality-Virtuality continuum. According to [10], this continuum includes four application fields:

1. Real Environment
2. Augmented Reality
3. Augmented Virtuality
4. Virtual Environment.

The first and the last images are the so-called continuum poles. They are well known from the real life (the first one) and with artworks or computer games (the second one). Images 2 and 3 apply to MR applications depending on whether the real world is immersed in the virtual or vice versa. In [1], AR was defined as follows:

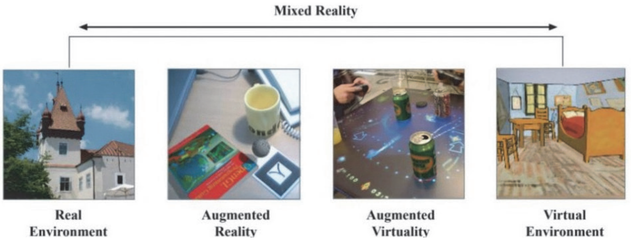

Fig. 1. Mixed Reality Continuum [10]
Rys. 1. Kontinuum Mieszanej Rzeczywistości

1) It combines both the real and virtual content,
2) The system is interactive and performs in real-time, and,
3) The virtual content is registered with the real world.

Augmented Reality is an enhanced, interactive version of a real-world environment. Augment Reality is applied when human work is supported in diagnostics and maintenance (Fig. 2).

According to the references [9], AR has been researched and developed for over 30 years. It is mainly used to support object tracking, maintenance and diagnostic activities, repairs and training [2, 5, 11, 12, 14]. In all these areas, the virtual world is embedded in the real world. The problem of mixing realities is different in the case of simulation issues. Here, the opposite situation occurs it is the real world that is added to the dominant virtual world to enrich the visual experience with tactile sensations. This is augmented virtuality (AV), which can be defined by modifying sentence 3) defining AR to “The real content is registered with the virtual world”.

An example of the system built based on the above assumptions is a simulator prototype of a Mi-17 helicopter designed by the Air Force Institute of Technology (AFIT) [3], which was illustrated in Fig. 3. In this simulator, the HTC Vive was used as a monitor. This device is dedicated to VR applica-

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tions and does not allow visualisation of real-world objects. AR monitors such as HoloLens, for example, allow this. However, these monitors have two main drawbacks that prevent their use in the simulator. The first is that the viewing angle is too small. For HoloLens, the field of view is 43° horizontally and 29° vertically [19], while for the HTC Vive, the angle of view both vertically and horizontally is 151.93°. As shown in [4, 8], a relatively small FOV is a feature of all current AR monitors. A second disadvantage is the design of AR monitors, which do not provide total immersion in the virtual world.

Fig. 2. Applying augmented reality in diagnostics and maintenance [12]
Rys. 2. Wykorzystanie poszerzonej rzeczywistości w diagnostyce i obsłudze

Fig. 3. Cockpit simulator in MR technology
Rys. 3. Symulator kabinowy zrealizowany w technologii Mieszanej Rzeczywistości

Therefore, the only solution is the use of VR monitors. Since, as previously mentioned, these monitors do not allow visualising real objects, digital twin technology was used to ensure correct interaction with the simulator. A digital twin can be defined as an intelligent technology platform for synchronising physical objects and digital objects, imitating them in (quasi) real-time [7]. Using this technology, both real objects and their digital twins coexist in the simulator. The real objects provide tactile sensations, while their digital twins provide visual sensations using VR monitors.

2. Formulating a problem

In the Mi-17 simulator, the virtual world is formed by the cabin with avionics equipment and its surroundings: terrain, airport runway, flight control tower, etc. Human-machine interaction occurs using real flight controls: control stick, collective-pitch lever and rudder pedals, which enable a human to control the simulated object. In response, he receives imagery of surroundings: view of one's own hands, cockpit and terrain view, rendered on Head Mounted Display in the form of virtual 3D objects. Objects affecting the sense of touch, such as the stick and the pitch lever, are visualised on the display as digital twins. Figure 4 shows a blending of the virtual and real worlds affecting the human eye and touch, respectively. The large frame shows the image the human sees in the VR monitor while the small one inside, surrounded by a red frame corresponding to the virtual one, shows the real world. The image shows the real control stick and its digital twin corresponding to it in the virtual world.

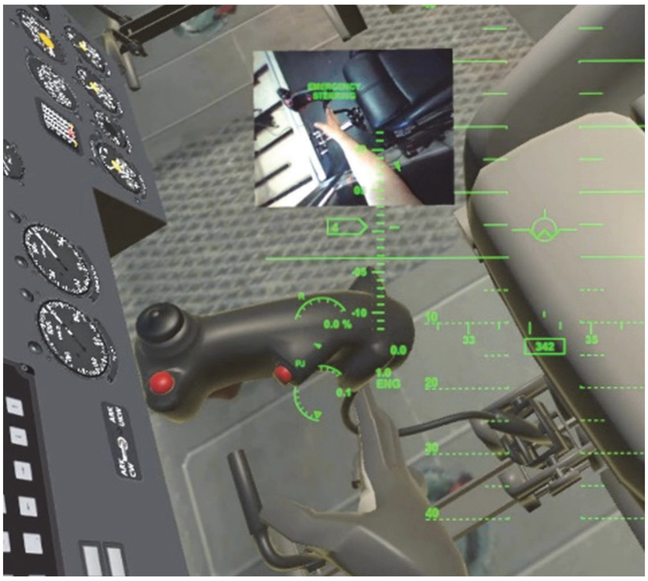

Fig. 4. Blending a real and a virtual world using digital twins
Rys. 4. Łączenie rzeczywistego i wirtualnego świata z wykorzystaniem cyfrowych bliźniaków

Pairs of real objects, such as the pilot's hand and the rudder stick, interact with each other, which must be matched by the interaction of their virtual counterparts, so it is extremely important to ensure high accuracy and consistency in the representation of both the shape and position of the virtual objects.

The actual control elements are a part of the Helicopter Flight Control Sets – Puma [15]. They represent certain $\tilde{B}_n \subset \Re^3$ bodies to which their digital $\hat{B}_n \subset \Re^3$ twins correspond, which are objects of the Unity 3D graphics engine [17]. To express a spatial description of these bodies, a homogeneous transformation matrix is used, which can be defined as follows:

$$\boldsymbol{A} = \begin{bmatrix} \boldsymbol{R} & \boldsymbol{T} \\ 0 & 1 \end{bmatrix}, \tag{1}$$

where $\boldsymbol{R}$ is a 3×3 orthogonal matrix and vector $T_n \in \Re^3$ [13].

Data on the position of flight controls are collected from their potentiometer sensors, which are transferred to the flight dynamics module via the USB port (Fig. 5). Then, the data are sent to the Visual Display System via Ethernet port (UDP protocol). Based on the obtained data, in the VDS module are updated transformation matrices (1) of Unity 3D graphical objects (Control Stick Transform), which estimate the transformation matrices of the real (simulated) flight controls $\hat{\boldsymbol{A}}_n$ and clearly define the position of the flight controls $\tilde{\boldsymbol{x}}_n \in \tilde{B}_n$.

Fig. 5. Location verification mechanism of the control units in the real and virtual world (mixed reality) for the control stick

Rys. 5. Mechanizm weryfikacji położenia organów sterowania w świecie rzeczywistym i wirtualnym (mieszana rzeczywistość) dla drążka sterowego

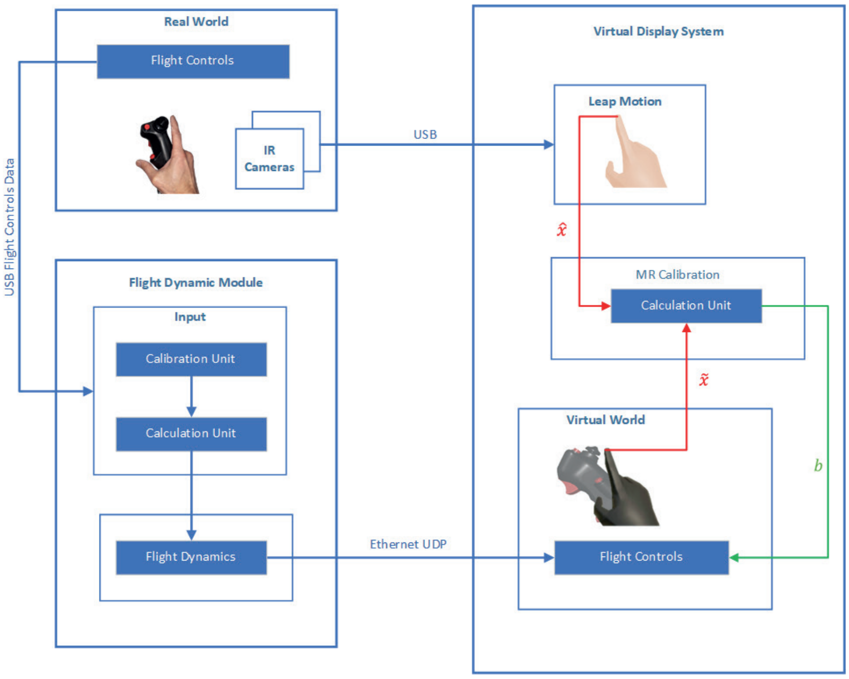

Fig. 6. Mismatch between the position of digital twin of the control stick and the virtual hand of the operator

Rys. 6. Niedopasowanie pozycji cyfrowego bliźniaka drążka do wirtualnej dłoni operatora

In the case of data related to the position of hands, the measurement path is different. Hands are recognised by LeapMotion [16] sensors, and their location is determined by two IR sensors and provided to VDS, where their positions are estimated $\hat{\boldsymbol{x}}_{left-hand}$ and $\hat{\boldsymbol{x}}_{right-hand}$. Due to the high accuracy of sensors (the manufacturer assures that the difference in positions of the virtual hand compared to its real counterpart is no more than a few millimetres [18]), their estimated positions were assumed to be equal to their real positions $\tilde{\boldsymbol{x}}_{left-hand}$ i $\tilde{\boldsymbol{x}}_{right-hand}$. In the case of control units, determining their positions is not so precise, and a mismatch error function defined by the formula appears:

$$d_i\left(\hat{\boldsymbol{x}}_i\right) = \hat{\boldsymbol{x}}_i - \tilde{\boldsymbol{x}}_i, \tag{2}$$

where: i – object index, d_i – mismatch function for i-th object.

The figure shows the visual effect of this mismatch occurring when the real hand grabs the control stick.

To remove this effect, calibration should be made to minimise the mismatch d by finding $\boldsymbol{b}_i \in \Re^3$:

$$\min d_i\left(\hat{\boldsymbol{x}}_i\right) = \wedge_{\hat{\boldsymbol{x}}_i \in \Re^3} d_i\left(\hat{\boldsymbol{x}}_i + \boldsymbol{b}_i\right) < d_i\left(\hat{\boldsymbol{x}}_i\right), \tag{3}$$

where: $\boldsymbol{b}_i$ – calibration vector for i-th object.

3. Mixed Reality Calibration

Condition (3) formulated in the previous section in practice applies to two pairs of objects: left-hand – pitch lever and right-hand – control stick. Therefore, for calibration purposes, two real-world reference points were chosen for which buttons were selected [15]: the “Coolie Hat” located on the control stick and the “Throttle-Cutoff” button located on the collective pitch lever. The location of the buttons is shown in Fig. 7.

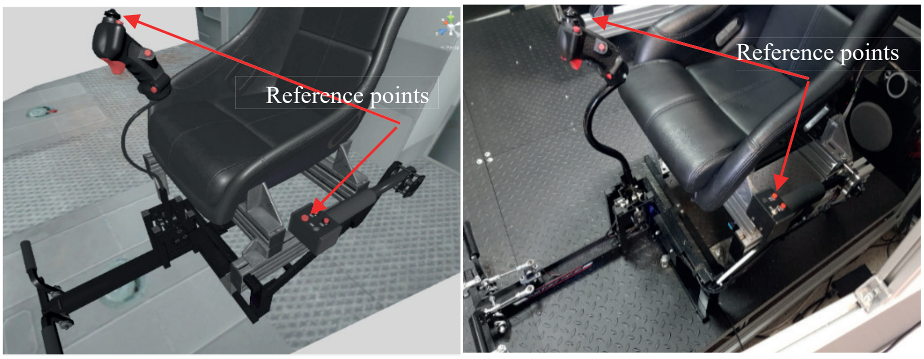

Fig. 7. Reference points: “Coolie Hat” button located on the control stick and “Throttle-Cutoff” button located on the collective pitch lever (on the left – virtual world, on the right – real world)

Rys. 7. Punkty referencyjne: przycisk „Coolie Hat” znajdujący się na drążku sterowniczym oraz przycisk “Throttle-Cutoff” zabudowany na dźwigni skoku ogólnego (z lewej - świat wirtualny, z prawej – świat rzeczywisty)

The calibration is done separately for the stick and the pitch lever and, in the case of the stick, involves placing the distal phalanx of the thumb of the right hand on the “Coolie Hat” button on the real control stick. Figure 6 shows that, due to the mismatch between the real and virtual worlds, the virtual right hand is not on the digital twin of the stick, but outside it. The calibration process is triggered by touching the virtual screen opposite the first pilot with the virtual hand. Calibration procedures are determined by vector $\boldsymbol{b}_{stick}$ (3). As a result of calibration, consistency between the imaging of the virtual objects and their originals is achieved, as shown in Fig. 8.

Fig. 8. Reconciling the position of the virtual hand and the digital twin as a result of MR calibration (hand and joystick on the light background)
Rys. 8. Uzgodnienie położenia wirtualnej dłoni i cyfrowego bliźniaka w wyniku kalibracji MR (dłoń i drążek na jaśniejszym tle)

Figure 9 shows the results of the obtained MR discrepancies for the control stick described in [3].

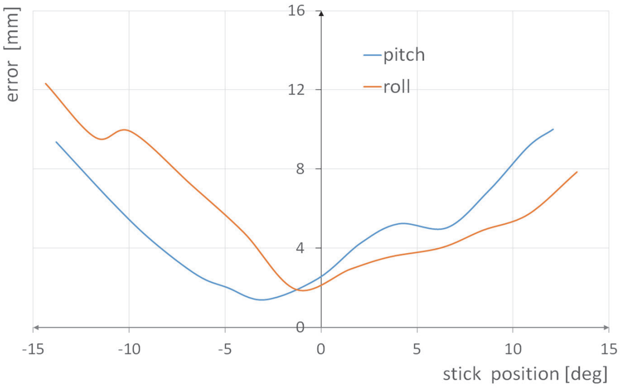

Fig. 9. Relation of a static error from the deflection of a control stick
Rys. 9. Zależność błędu statycznego od wychylenia drążka

The error changes range from 2 to 12 millimetres. In our case, the error increase is due to the mismatch of the real control stick with its virtual counterpart. A virtual control stick, although it can be extended, doesn’t enable the change of the position of its attachment point in relation to the object-parent. Thus, it is impossible to change the location of its pivot point in relation to the entire object, i.e., flight control. It results in the fact that either the frame of the control system or the attachment point of the control stick will be matched to the aircraft model.

4. Summary

This paper presents the aspect of using mixed reality in aircraft simulators. In contrast to other areas of application of this technology, such simulators require a very large ‘share’ of the virtual world, which consists of the interior of the aircraft, its equipment, and its surroundings: terrain ground objects and other simulated objects. We are, therefore, dealing with augmented virtuality, in which the real world is added to the virtual world to extend the impact of the simulator on the sense of touch.

To realise this goal, a VR monitor was used. To visualise the real objects of the flight controls, their digital twins were used. LeapMotion sensors were used for hand detection, localisation, and visualisation. A method is presented to remove discrepancies in the positions of the virtual objects relative to their originals so that the image on the VR monitor is consistent with the real situation. The results of the mapping accuracy measurement presented in the paper [3] confirmed the satisfactory accuracy of the calibration performed.

From the reliability perspective, the use of LeapMotion sensors for hand localisation and 3D reconstruction has its major drawback. Proper operation is possible when the hands are clearly visible in the lens of the two infrared cameras. If part of the hand is obscured by other real objects (e.g., the control stick), the hand may display inaccurately, incorrectly or disappear altogether. The use of VR gloves can be adopted as an alternative solution.

In conclusion, using VR monitors in combination with digital twin technology is an appropriate solution for the implementation of an aircraft simulator in MR technology.

References

1. Azuma R., *A survey of augmened reality.* “Presence: Teleoperation and Virtual Environments”, Vol. 6, No. 4, 1997, 355-385, DOI: 10.1162/pres.1997.6.4.355.
2. Farasin A., Peciarolo F., Grangetto M., Gianaria E., Garza P., *Real-time Object Detection and Tracking in Mixed Reality using Microsoft HoloLens*, Proceedings of the 15th International Joint Conference on Computer Vision, Imaging and Computer Graphics Theory and Applications (VISIGRAPP 2020), Vol. 4: VISAPP, 165-172, DOI: 10.5220/0008877901650172.
3. Golański P., Szczekala M., Roguszewski M., *Analysis of the 3D Object Reconstruction Accuracy in an Mi-17 Mixed Reality Simulator*, Automation 2021: Recent Achievements in Automation, Robotics and Measurement Technique, Vol. 1390, 136–145, DOI: 10.1007/978-3-030-74893-7_14.
4. Guttag K., *FOV: AR and The View of the Real World*, KGOnTech, https://kguttag.com/.
5. Haller M., Billinghurst M., Thomas B., *Emerging technologies of augmented reality – interfaces and design*, Idea Group Inc., 2007.
6. Henderson S., Feiner S., *Exploring the Benefits of Augmented Reality Documentation for Maintenance and Repair,* “IEEE Transactions on Visualization and Computer Graphics”, Vol. 17, No. 10, 2011, 1355–1368, DOI: 10.1109/TVCG.2010.245.
7. Jeong D.-Y. et al., *Digital Twin: Technology Evolution Stages and Implementation Layers with Technology Elements*, “IEEE Access”, Vol. 10, 2022, 52609–52620, DOI: 10.1109/ACCESS.2022.3174220.
8. Kress B.C., *Digital optical elements and technologies (EDO19): applications to AR/VR/MR*, Proceedings SPIE 11062, Digital Optical Technologies 2019, DOI: 10.1117/12.2544404.

9. Mackay W.E., *Augmented reality: linking real and virtual worlds: a new paradigm for interacting with computers*, AVI '98: Proceedings of the working conference on Advanced Visual Interfaces, 1998, 13–21, DOI: 10.1145/948496.948498.
10. Milgram P., Kishino F., *A taxonomy of mixed reality visual displays*, IEICE Transactions on Information Systems, E77-D (12), December 1994.
11. Prokopiuk N., Falkowski P., *Applicability of augmented and virtual reality for education in robotics*, "Journal of Automation, Mobile Robotics and Intelligent Systems", Vol. 16, No. 3, 2022, 65–74, DOI: 10.14313/JAMRIS/3–2022/25.
12. Szczekala M., Mądrzycki P., *Zastosowanie technologii rozszerzonej rzeczywistości do doskonalenia procesów szkoleniowych*, „Technika Transportu Szynowego", Vol. 20, No. 10, 2013, 93–102, DOI:10. 13140/RG.2.1.2652.6565.
13. Tchon K., Muszynski R., Mazur A., Duleba I., Hossa R., *Manipulators and mobile robots – models, traffic planning, control.* AOW PLJ, Warszawa 2000.
14. Wójcicki T., *Supporting the diagnostics and maintenance of technical devices with augmented reality*, "Diagnostyka", Vol. 15, No. 1, 2014, 43–47.

Other sources

15. Der PUMA Helicopter Controller, https://docplayer.org/193087430-Der-puma-helicopter-controller.html.
16. Ultraleap Ltd. LEAP Motion, Documentation. developer.leapmotion.com/documentation.
17. Unity, unity.com.
18. HTC Corporation, vive.com/us/support/vive.
19. Microsoft HoloLens 2 – main features, use cases, benefits, https://nsflow.com/blog/microsoft-hololens-2-main-features-use-cases-benefits.

Zastosowanie technologii cyfrowych bliźniaków w symulatorze mieszanej rzeczywistości śmigłowca Mi-17

Streszczenie: Artykuł dotyczy zagadnienia łączenia świata rzeczywistego ze światem wirtualnym w symulatorach Mieszanej Rzeczywistości (MR). Rzeczywistość mieszana pozwala na integrację świata rzeczywistego ze światem wirtualnym – obiektów rzeczywistych z obiektami generowanymi komputerowo. Osoba wchodząca w interakcję z takim systemem otrzymuje zarówno wrażenia wizualne, jak i dotykowe. Aby zapewnić właściwą interakcję z elementami systemu, konieczna jest duża dokładność rekonstrukcji obiektów wirtualnych w stosunku do odpowiadających im obiektów rzeczywistych. Artykuł przedstawia koncepcję łączenia świata rzeczywistego i wirtualnego z wykorzystaniem kombinacji technologii VR i Digital Twins oraz ma na celu zilustrowanie, w jaki sposób zapewnić wysoką zgodność odwzorowania obiektów wirtualnych w stosunku do ich rzeczywistych oryginałów, na przykładzie symulatora śmigłowca Mi-17 wykonanego w technologii MR.

Słowa kluczowe: Mieszana Rzeczywistość (MR), Wirtualna Rzeczywistość (VR), symulator śmigłowca Mi-17, Unity 3D, Cyfrowe bliźniaki

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