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GAP FILLING ALGORITHM FOR MOTION CAPTURE DATA TO CREATE REALISTIC VEHICLE ANIMATION

Abstract

The dynamic development of the entertainment market entails the need to develop new methods enabling the application of current scientific achievements. Motion capture is one of the cutting-edge technologies that plays a key role in movement and trajectory computer mapping. The use of optical systems allows one to obtain highly precise motion data that is often applied in computer animations. This study aimed to define the research methodology proposed to analyze the movement of remotely controlled cars utilizing developed gap filling algorithm, a part of post-processing, for creating realistic vehicle animation. On a specially prepared model, six various types of movements were recorded, such as: driving straight line forward, driving straight line backwards, driving on a curve to the left, driving on a curve to the right and driving around a roundabout on both sides. These movements were recorded using a VICON passive motion capture system. As a result, three-dimensional models of vehicles were created that were further post-processed, mainly by filling in the gaps in the trajectories. The case study highlighted problems such as missing points at the beginning and end of the recordings. Therefore, algorithm was developed to solve the above-mentioned problem and allowed for obtaining an accurate movement trajectory throughout the entire route. Realistic animations were created from the prepared data. The preliminary studies allowed one for the verification of the research method and implemented algorithm for obtaining animations reflecting accurate movements.

1. INTRODUCTION

Realistic movement mapping is a rapidly developing technology applied in the medical (Liu et al., 2020; Lam et al., 2023), film, gaming (Chung et al., 2022), and sport industries (Skublewska-Paszkowska et al., 2022). This matter involves the usage of appropriate methods to obtain the best possible results that will be distinguished by high accuracy and realism. The significant aspect is to ensure that the created model or motion animation provides an incomparable representation of authentic behavior. This approach could leave a mark on the attractiveness of the object for an observer and enhance the user's immersive experiences (Praveen & Srinivasan, 2022).

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Among many movement mapping methods, motion capture systems are currently the most valuable technology, which provides high-accuracy results in the capability to portray depth and realness in 3D space (Lopez et al., 2024). Depending on the selected type of system, it is possible to explore appropriate phenomena and obtain a mapped image of reality in the space of computer vision. The variety of motion capture systems enables some flexibility in choice, utilizing electromechanical, optical marker, inertial or optical markerless systems (Sharma et al., 2019).

Each technology has its advantages, but also disadvantages that cannot be overlooked. One of the highest efficiencies identifies passive optical ones based on a system of cameras emitting infrared light (Salonen, 2021). However, when looking at the disadvantages, it is worth emphasizing the common issue – integration between different software or 3D models, which is a demanding and time-consuming process that requires the use of additional technologies. Developing a proper 3D model based on the obtained marker trajectory involves several stages and may cause many challenges in the case of poor-quality datasets.

This study aims to elucidate the methodology for the process of acquiring high-fidelity recordings of remotely controlled vehicles using an optical motion capture system, and in further post-processing, obtaining high-quality 3D model animation. The key element of the study is the development of a postprocessing algorithm to eliminate gaps in marker signals at the beginning and the end of the recordings. The significant matter is the appropriate guidance of the registering area and research objects. The study utilizes a Vicon (Vicon, 2024) passive optical system, which enables the recordings. The created dataset is post-processed using Nexus (Vicon, 2024, May 24) software. As a result of implemented algorithm, accurate data were obtained. The final stage of the study was the development of a 3D model animation using Vicon Tracker technology.

2. RELATED WORKS

Currently, the majority of researchers focus on the possibilities of various applications of motion capture technology. They take into consideration how diverse the application of this method can be in multiple industries, not only scientific but also everyday life, for example including improvements in workplace ergonomy (Lugrís et al., 2023). This section describes committed studies in this area.

Motion capture (Mocap) is widely used in motion analysis methodologies (Smirnova et al., 2022; Skublewska-Paszkowska et al., 2012; Smołka & Skublewska-Paszkowska, 2014). Publication (Sharma et al., 2019) focuses on presenting possible types of this technology, including marker-based and markerless Mocap. The authors discuss the advantages and disadvantages of each, in terms of both convenience and possible obtained results. Additionally, the authors describe the challenges that may be encountered in work with movement capturing systems, containing the most important ones: 1) divergence of limited formats, 2) real-time visualization problem, 3) movement and space restrictions, 4) equipment and related costs, 5) the need to post-process result data.

Acquiring data utilizing Mocap system can be an effective way of collecting datasets in high accuracy (Lopez et al., 2024), but sometimes it brings some disadvantages in the form of complete absence or incorrectly recorded signals of markers, noise, caused by reflections, or electromagnetic interference. Additionally, some Mocap systems could generate drifts – a gradual deterioration in the accuracy of marker positions, and motion artifacts that do not represent real movements but some random vibrations of infrared reflection. However, with the development of movement mapping technology, researchers create techniques, and algorithms that can eliminate inaccuracies and obtain high-quality data, for example (Ardestani & Yan, 2022) used the B-spline-based least square method, which allowed for obtaining smoothed, noise-free signals.

Mocap has a wide range of applications, but each type could bring the challenges and limitations. The most frequently used technology are optical systems that allow for achieving high data quality and high accuracy in mapping real trajectories in computer space, as indicated in (Skublewska-Paszkowska et al., 2020; Skublewska-Paszkowska & Powroznik, 2023,) aggregation of tennis strokes. This proves that optical Mocap systems are a powerful tool for acquiring motion data. Their diversity is caused by different instrumentation configurations. The authors of the publication (Topley & Richards, 2020) discuss the dependence of system specifications and the influence of camera configuration on the obtained dataset results. They pointed out differences in the effects of the acquired data, comparing some of the currently available optical systems with the first optical technologies. It turned out that the newly developed systems show greater accuracy and smaller errors and deviations of the data in comparison to the actual measurements.

Among wide applications of movement mapping such as ergonomics, games, and medicine, we can also find animations. The authors of (Wibowo et al., 2024) discuss the possibility of using the motion capture technique to produce animations. In addition to practical application, the challenges and limitations that meet creators were also discussed. The most important of them is the complexity of the data and the possibility of its integration with other analytical systems. It was pointed out that there is a serious problem in integrating data with 3D animation software. Numerous publications (Asraf et al., 2020; Zhu, 2019) indicate the possibilities of creating animations based on Mocap systems, some of them allow tracking and mapping of movement in real time (Rupnawar et al., 2024), which is a big step forward in building virtual reality applications.

The publication (Guo & Zhong, 2022) describes the assumptions of creating animation for films using a modern motion capture approach. The authors describe the process in subsequent stages, taking into account the theoretical base of computer vision. They describe the process of integrating motion capture data using the example of a humanoid figure. However, current research does not indicate the use of motion capture to create rigid body animations.

A particularly important aspect when creating animations is their realism and reflecting the depth of movement. Study (Naik et al., 2023) has shown that properly made animations increase user engagement. They can attract and make aesthetic and visual feelings affect the memorability and usability of the created objects. This matter is particularly important when projects are commercial products and their creators want the highest possible profit, because it can make them more attractive to users, making them willing to try visual experiences. The most spectacular effects are those of motion animations, drastic state changes, immersive effects, and unexpected actions that provide the greatest results in improving the attractiveness of works, as indicated (Yun et al., 2021). That is why the use of appropriate technologies is so important in creating animations.

In the article (Lei, 2019) it is shown that motion capture systems are a key component in enhancing the level of realism in the world of 3D animation. They transfer real movements into computer space,

Various tools are used to integrate the acquired data and use them to create animations. The publication (Mousas & Anagnostopoulos, 2017) identifies Autodesk software such as 3ds Max (Autodesk, n.d. a) and Maya (Autodesk, n.d. b) for creating computer instances of real objects as a versatile solution using the example of realistic hand movements. It is also said that in addition to technologies such as motion capture, there are more affordable methods, including Intel RealSense (2024), but they are ineffective and cannot provide the required accuracy.

Despite such a wide development of motion capture applications, most applications are based on humanoid models representing data in 3D space. It is difficult to find data on the applications of this technology in rigid body mapping and animation. The most common methods refer to traditional methods using computer simulations without additional trajectories mapping trajectories (Cao et al., 2020).

The literature review indicated that Mocap techniques are a powerful movement analysis tool that can be utilized to obtain high-quality data for use in creating animations based on actual trajectories. Despite such a wide application, most research concerns humanoid silhouettes, not rigid body models such as vehicles. That is why the authors of this study have taken up the challenge to create realistic vehicle models based on Mocap data.

3. METHODOLOGY OF THE STUDY

The main part of the study is to create a methodology for registering vehicle movements (Fig.1) using the Vicon motion capture system. The obtained three-dimensional data together with their trajectories were used to develop the realistic 3D vehicle animations.

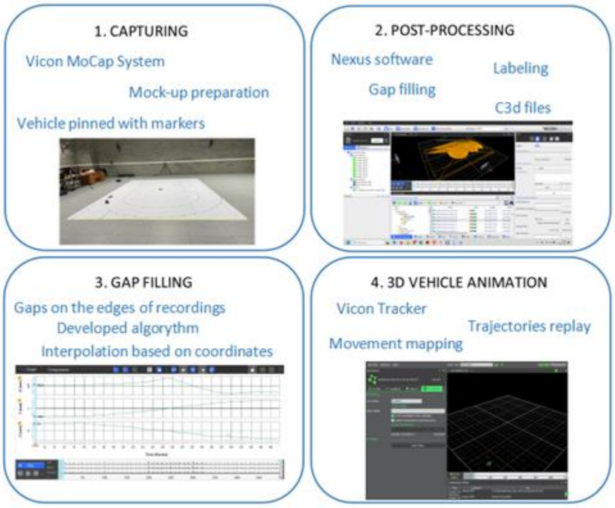

Fig. 1. Proposed study methodology

3.1. Mockup and movement routes

Initially, a research area was prepared covering the mockup with a driving model (Fig.2). The surface contained marked tracks for 6 types of movement: straight forward, straight backward, driving on a curve to the left, driving on a curve to the right, around the roundabout to the left and right. The entire mockup was pinned with properly measured markers of diameter 14mm. On routes, markers were placed parallel on both their sides. The distances between the markers were determined experimentally so that their connection could give the actual shape of the road in the computer representation, but they were not too dense to avoid disturbing the signal of the riding vehicle markers. The total size of the model was 3.40m x 5.40m and was placed in the center of the laboratory.

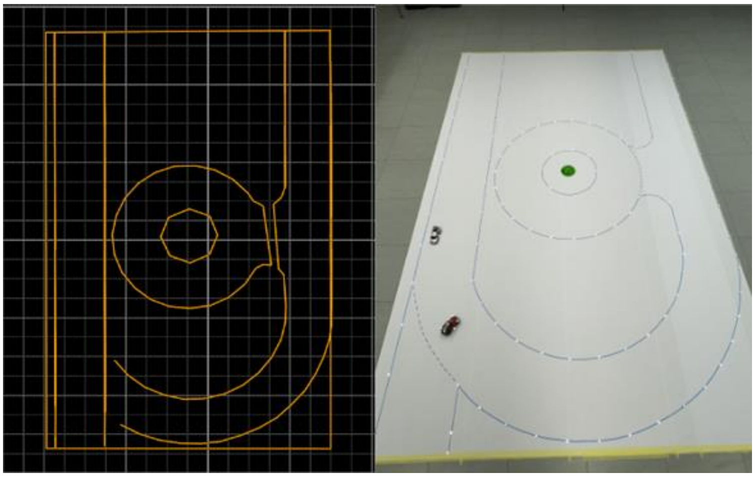

Fig. 2. The mockup with movement routes – in Vicon software (left picture) and real life (right picture)

3.2. Vehicle subject

The research objects consist of vehicles pinned with markers at seven points. The reflective part of the marker has a diameter of 14mm. Their locations were chosen in such a way as to enable the reproduction of a rigid body in 3D space. Two markers have been placed on the front, two on the sides, two on the rear and one on the center top of the car roof. Markers are placed symmetrically on the left and right side of the vehicle (Fig.3, Fig.4).

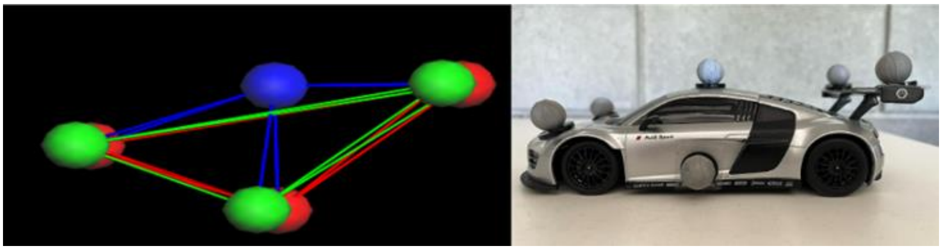

Fig. 3.The location of markers attached to the vehicle – in Vicon software (left picture) and real life (right picture)

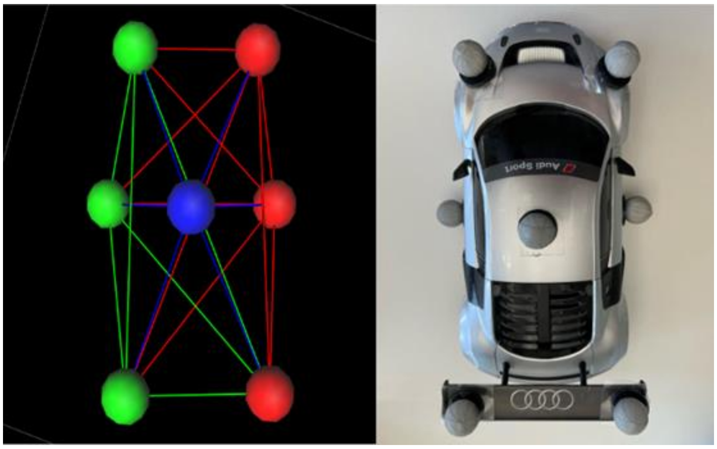

Fig. 4. The location of markers attached to the vehicle from top side – in Vicon software (left picture) and real life (right picture)

3.3. Research tool

The study was conducted in a laboratory equipped with an 8-camera Vicon passive optical system, which using reflecting infrared light, illuminates markers in the registering area. The cameras are arranged based on a specific spatial plan and ensure the registration of markers from all angles in 3D space. The area of 3.4 m x 5.4 m was covered with a prepared mockup (Fig.5).

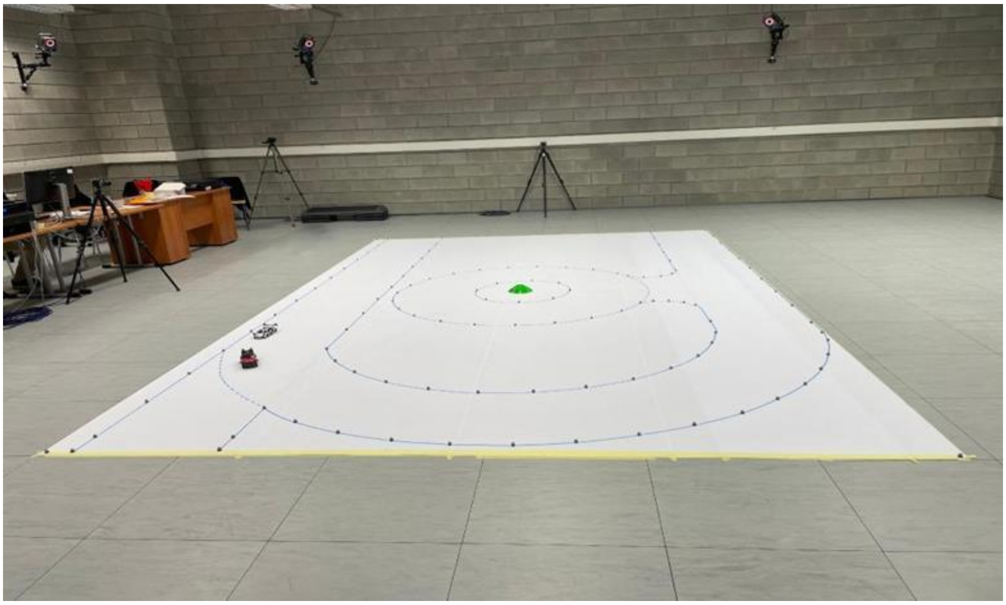

Fig. 5. The registering area covered with a created mockup

3.4. Vehicle movement capturing

The capturing procedure is presented in Fig.6. After setting up the laboratory, the next step was calibration of the camera system. This process recalculated positions of referencing points and improved visibility of markers signals. Then preliminary study began, which involved collecting datasets consisting of recordings of vehicles driving on the mockup. Each of the six planned moves has a sample of 5 correct runs. The movements were registered with the frequency set to 100Hz. The process is carried out using Nexus software, thanks to which the collected data can be easily post-processed.

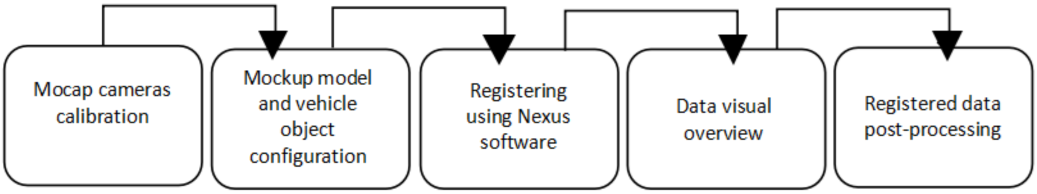

Fig. 6. The vehicle movement capturing procedure

3.5. Data post-processing

Post-processing is a significant step for obtaining clean and accurate data applied for further analysis and integration with other sources. The recorded data has some artifacts that need to be corrected. The post-processing required several steps:

- Visual review of recordings – looking for signal errors, missing markers, noise and artifacts,
- Markers labeling – creating labels, assigning names to a given marker location and combining markers into configurations of real objects,
- Filling in gaps – detection and removal of gaps in recordings that were caused by infrared incorrect light reflection,
- Deleting mistakenly placed markers – removing artifacts and markers that are unnecessary in the model.
- The software fills in gaps in the middle of the recordings, but not on the edges. Nexus needs point signal before and after the gap to eliminate it.

3.6. Gap filling algorithm

After capturing the vehicle movements, the gaps in the trajectories were observed, mainly at the beginning and end of the recording. That is why, there was a need to find a solution enabling obtaining accurate and completed samples. A piece of software was implemented that consisted of separate functions. The first one involved loading motion capture data from a c3d file using the Python library. Then, the file structure was reviewed. Each file has 3 sections: header, parameter and data. The last one is the most important in retrieving data. It contains information about frames of recordings. Each frame was supplemented with the coordinate data of the appropriate markers. In this way, it was determined that the missing signals were marked as 0. The key feature of the model that the algorithm uses is the fact that it is a rigid body object, which means that the distances between the designated points are constant regardless of the motion.

The gaps could be filled if selected file provided the possibility of obtaining data on at least 3 other points signals of the vehicle's rigid body.

The gap filling algorithm for the missing markers in the beginning and in the end of recordings is depicted in Fig.7.

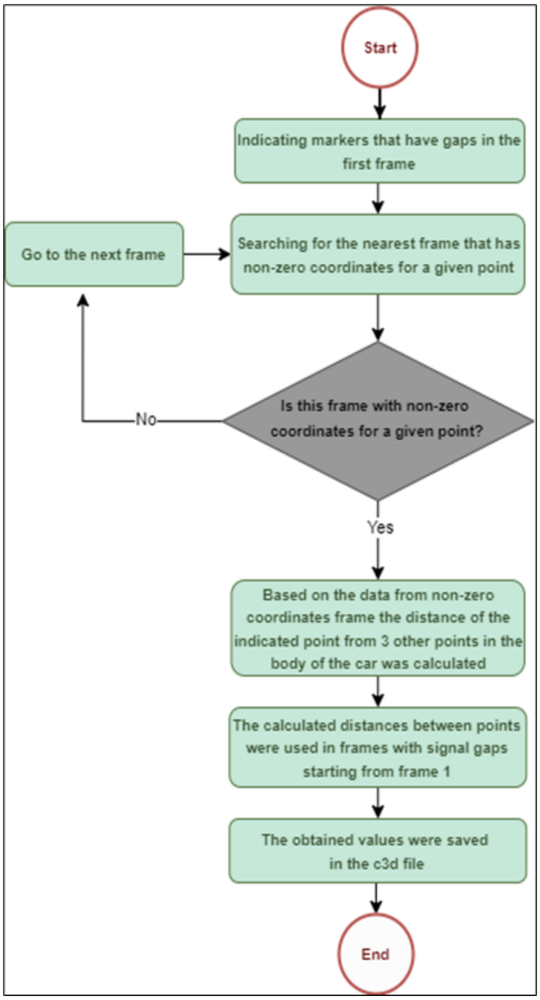

Fig. 7. The schema of gap filling algorithm

3.7. Creating 3D vehicles animation

Based on the received data, the animations for all routes were developed. The usage of Vicon Tracker 3.1 (Vicon, May 24b) software allows one to upload motion capture files and create animation of movement.

Once the data was loaded, the signals for all markers were visible for subsequent frames. The next stage was to create an object that should be mapped to specific markers, adding further instances of the object's elements and giving them a label. After uploading the recording and preparing the object, it was necessary to map specific positions in the 3D view to the positions of the object's elements. Created object was integrated with movement routes and in result it reproduced realistic movement of a vehicle.

4. RESULTS

The results of this study are both the collected dataset of motion capture recordings (Fig.8) and created animations reflecting the real movements of the recorded vehicles. The developed gap-filling algorithm made it possible to complete the trajectories at the beginning and end of the recording and thus to obtain continuous and accurate movement trajectories.

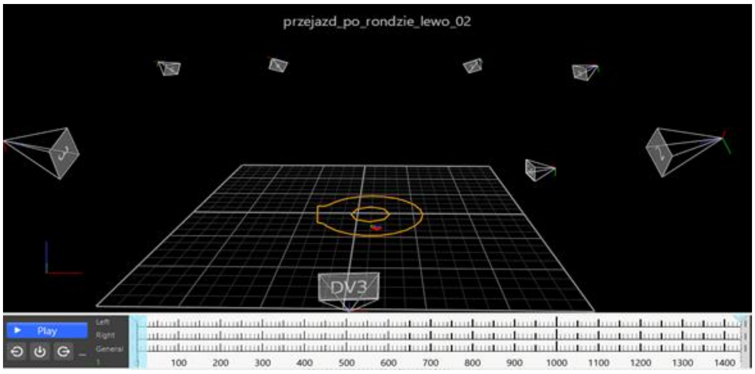

Fig. 8. The Nexus software view of sample recorded data

4.1. Obtained dataset

The collected dataset consisted of six movements: straight forward and backward, on the curve to the left and to the right and around a roundabout on both sides. While motion registration, all incorrect recordings, i.e. during which the movement was interrupted or the vehicles left the route or a certain area, or there was a collision with a marker attached to the model, were excluded from the dataset and further study.

The Nexus software permits to register point coordinates in 3D space. After selecting appropriate markers, a set of trajectories marked in X, Y, Z dimensions was obtained for subsequent types of movement. Each color line on the graph corresponds to a specific marker. The move around the roundabout is most riveting in terms of the X and Y trajectories, which resemble a sinusoidal shape (Fig.9, Fig.10). The Z plot, however, is more similar to a straight line, which shows constancy in the Z plane.

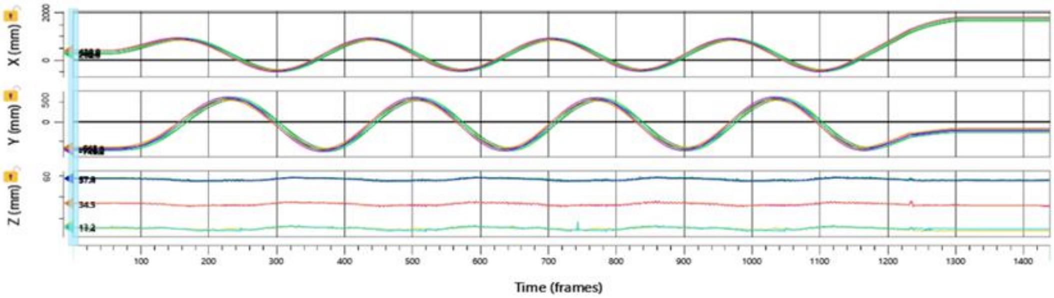

Fig. 9. Trajectories of movement – around the roundabout on the left

The movement around a roundabout (Fig.10) to the right has a greater amplitude, which could be directly influenced by the vehicle's axle settings or steering method.

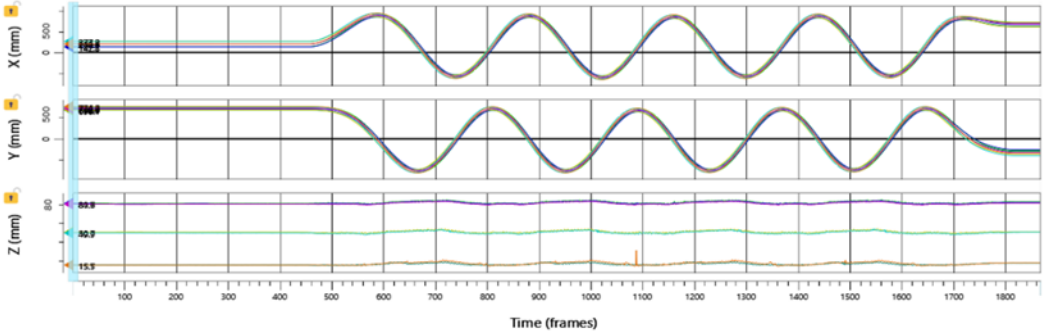

Fig. 10. Trajectories of movement – around the roundabout on the right

The next movement was to drive on a curve to the left and right (Fig.11, Fig.12). Most of the route consisted of driving straight until the vehicle entered a bend, after which it returned to driving straight. This movement configuration is visible on the graph in X and Y trajectories.

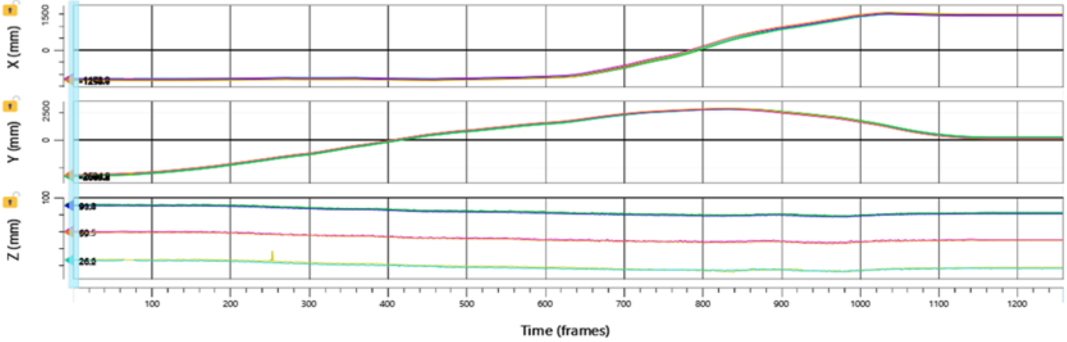

Fig. 11. Trajectories of movement – on a curve to the right

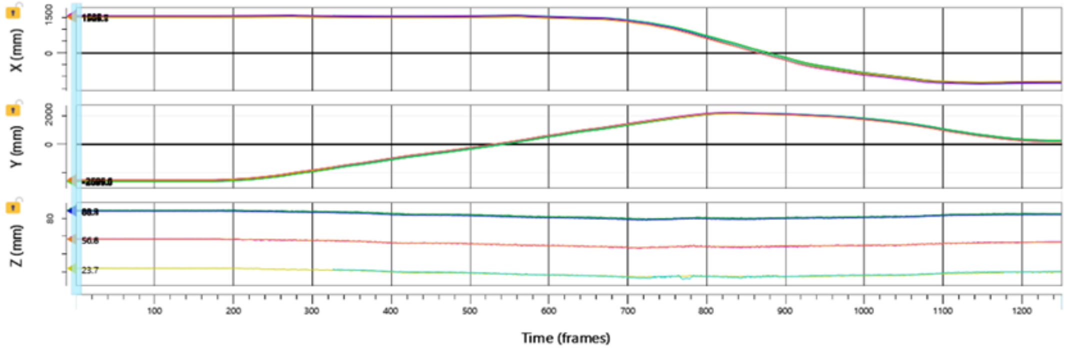

Fig. 12. Trajectories of movement – on a curve to the left

The last movement was to ride straight backwards and forwards. Due to the steering problems of the vehicle, it was necessary to correct the driving route, especially while approaching the marked edges. Ideally, the X and Y trajectories of the straight track, both backward and forward, should represent diagonal straight lines, but due to motion corrections, the lines in the graph are polygonal chain shapes (Fig.13, Fig.14).

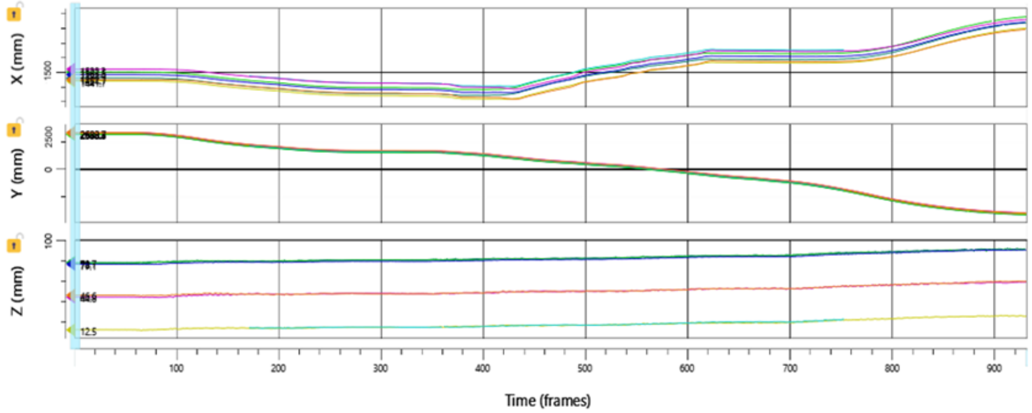

Fig. 13. Trajectories of movement – straight backwards

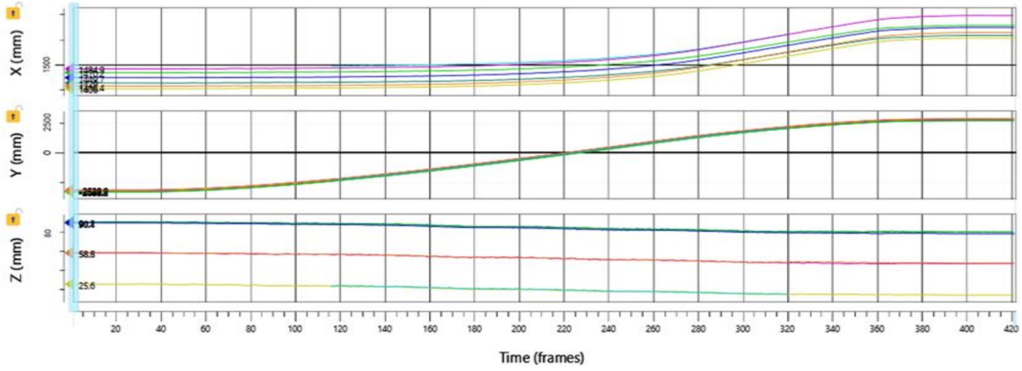

Fig. 14. Trajectories of movement – straight forwards

4.2. Gap filling

Since the Vicon software does not allow gap filling in the vehicles trajectories at the beginning and end of the recording, the authors developed their own algorithm for this purpose. A graph of the raw signal coordinates of an example vehicle marker is shown in Fig.15. As it can be observed the trajectories do not reflect the entire movement. The developed algorithm was run after post-processing, therefore the signal was continuous in the middle of the recording.

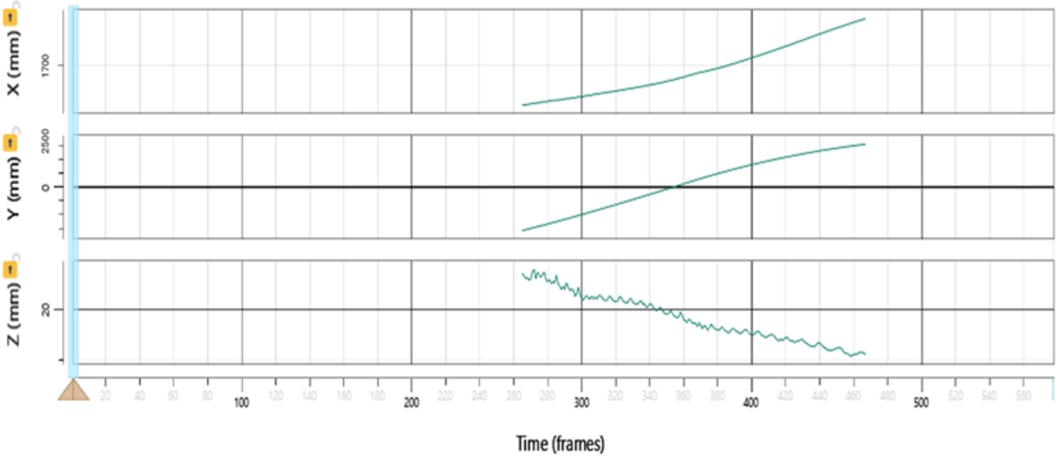

Fig. 15. Gaps on the edges of movement trajectories

After completing the data with our own algorithm, it can be seen that the trajectories have been completed correctly. Moreover, they are smooth, which confirms that the developed algorithm is suitable for this type of data. The filled trajectories are presented in Fig.16.

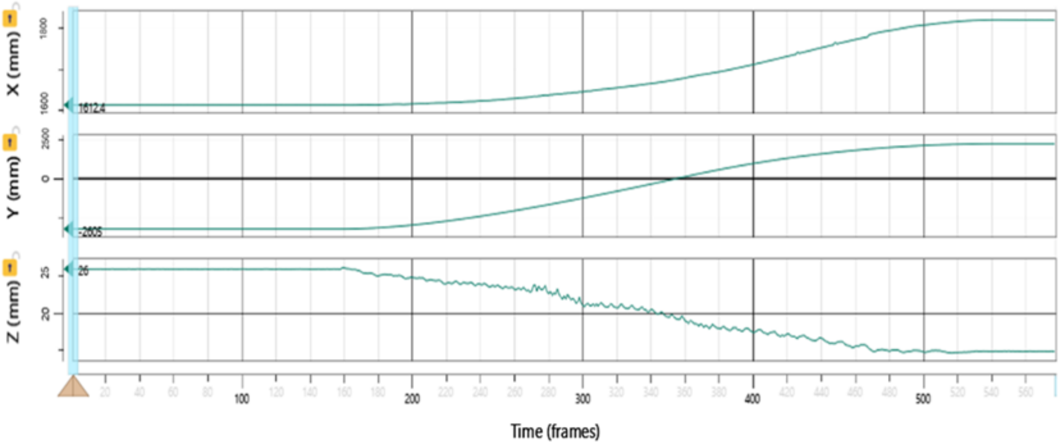

Fig. 16. Filled-in trajectories of movement

In order to confirm the correctness of the received complementation, a signal of one marker in a specific number of frames – 10, 50 was removed from the 3 full recordings, then developed algorithm was applied. The results enable to calculate linear deviations from the initial values, and to perform a student's t-test. The results are presented in Table 1. The obtained values prove the high efficiency of the algorithm.

Table 1. Calculated statistical values of linear deviation and student's t-test

	Marker coordinate	Linear deviation		T-test (*p* value)	
		10 frames	50 frames	10 frames	50 frames
Recording 1	X	0,0091	0,0174	0,0005	0
	Y	0,0166	0,036	0	0
	Z	0,0168	0,0189	0,0141	0,0002
Recording 2	X	0,0248	0,0536	0,0026	0,001
	Y	0,023	0,0473	0,0027	0,001
	Z	0,0138	0,0238	0,0013	0,002
Recording 3	X	0,0469	0,0288	0,0057	0,1935
	Y	0,0246	0,0225	0,0975	0,0002
	Z	0,0262	0,0259	0,0003	0

4.3. 3D vehicle animations

Computer animation, combined with advanced 3D scanning techniques, enables the creation of highly realistic and dynamic digital models for various applications, ranging from entertainment to intangible cultural heritage. These technologies use precise geometric and texture data, allowing for integration of virtual objects into the real-world environments (Skublewska-Paszkowska, et al., 2023; Powroznik et al., 2022).

Using the Vicon Tracker, an initial image of realistic movements of an object in the shape of a vehicle was obtained, which is presented in Fig.17, Fig.18 and Fig.19. Software permits tracking the trajectory of marked points, so in addition to the visual representation of markers, the movement route is detailed in the form of blue lines.

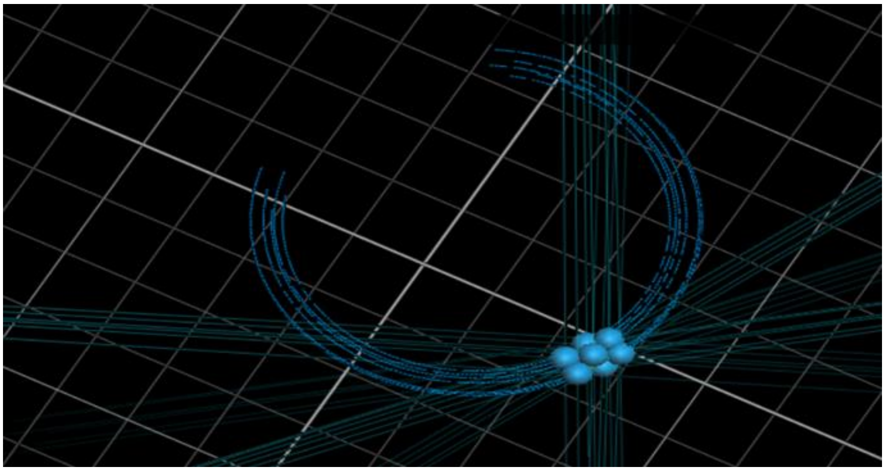

Fig. 17. Animation of movement – around a roundabout

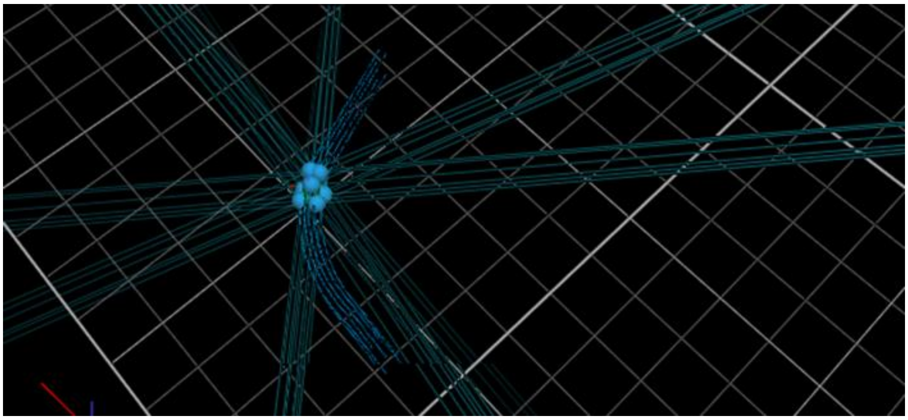

Fig. 18. Animation of movement – on the curve

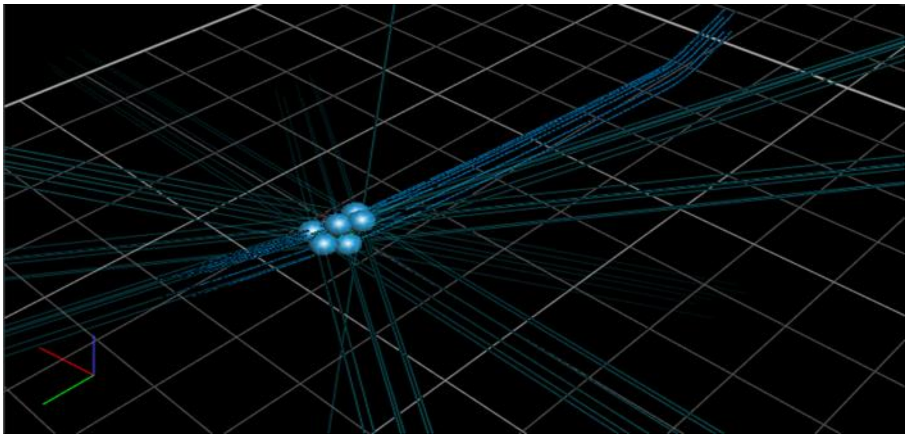

Fig. 19. Animation of movement – in straight

5. CONCLUSIONS AND FUTURE WORKS

Motion Capture is a cutting-edge technology that permits capturing precise movement trajectories. This is particularly important when reproducing the movement of people and objects, which is why Mocap is used in animation. Research so far focuses on humanoid figures. However, among numerous publications it is difficult to find materials on rigid bodies.

This study aimed to determine an effective methodology that would allow for recording the movement of remotely controlled vehicles and then implement proprietary algorithm to obtain full track of registered marker signals. The last stage was to create a model and animation in three-dimensional space. Preliminary study was based on the specified methods: 1) preparation of mockup and cars by covering with markers and measuring them, 2) calibration of the laboratory, including the eight-camera Vicon optical system, 3) recording of the vehicle's movement along the designated routes of the model, 4) post-processing using Nexus software, 5) creating a complementary algorithm using Python, which is filling in gaps in the beginning and at the end of recordings, 6) transferring data to Vicon Tracker, 7) creating a model and initial 3D animation.

In the presented study, the size of the model plays a major role. The Vicon system requires the dimensions of the objects on the basis of which the model will be created in 3D space. Therefore, both the mockup and the cars are specially measured for the purposes of the study. Changing the size of the model would affect the obtained results.

The methodology turned out to be successful and allowed for obtaining high-quality motion recordings. The preliminary study permits to verify the gap-filling algorithm, which turned out to be an effective solution that allows for achieving a continuous path of marker signals, and as a result improves the quality of recordings. The received data was utilized to create an animation, which is the first stage of work on creating a realistic representation of the vehicle's trajectory.

The conducted study constitutes an important basis for future research work. Further implementations will concern data integration with the possibility of adding a graphical representation of cars using appropriate 3D graphics software. The use of a trajectory and an appropriate 3D model will permit obtaining a precise object with realistic features. The biggest challenge is the integration of data from Mocap files, which must be properly mapped to the rigid body. This approach is key to achieving high animation accuracy.

The preliminary study allowed the completion of datasets that can be used to analyze movement and deviations while driving, which is also a future implementation. Current studies often include considerations on movement and its animation in real time, which is a trong development direction. This is especially noticeable in the case of VR technology.

Author Contributions

The paper conceptualization, methodology, software, formal analysis, investigation, resources, writing the original draft preparation, visualization, have been done by both authors equally.

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Conflicts of Interest

The authors declare that they have no conflict of interest.

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