# Opportunities and Current Obstacles to use MOVE4D for Cycling Analysis

Alexander VAN GASTEL *, Stijn VERWULGEN **
University of Antwerp, Antwerp, Belgium

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## Abstract

In this white paper, the opportunities and current obstacles to use the Move 4D markerless motion tracking system (Instituto de Biomecánica de Valencia- IBV), for capturing human product interactions is discussed. In particular, this whitepaper focuses on scanning cyclists to map and improve biomechanical efficiency and aerodynamics. If successful, it could lay the technological foundation to extend current CFD (computational fluid dynamics) analyses, with flow simulations executed with a dynamically moving body and bicycle based on a high resolution and high framerate 4D mesh. Furthermore, the homologous mesh export function could allow bike fitters to use digitally standardized measurement points for biomechanical assessments. In contrast, marker-based motion tracking systems require hand placement of markers that are susceptible to faults such as placement position errors, low battery while recording, and falling off the skin. A markerless system could also improve flexibility for researchers to find new relevant measurement points due to the flexibility of digital markers. Current obstacles are revealed during an exploratory observation: 1) recording a professional time trail rider. A primary obstacle in capturing human product interactions is that the system does not provide a usable homologous mesh, due to the system's inability to separate the object, in this case, the bicycle, from the cyclist. Two follow-up observations explore the effect of coating objects, used in human-product interactions, with material that do not emit infrared (IR) in broadbands of 3–5 μm and 8–14 μm: 2) exploring coatings that avoid detection by IR cameras, and 3) recording a human product interaction with an object coated in a material that avoids detection by IR cameras. Results shows that these coatings on objects used in a human product interaction enables the system to capture the actor's full dynamic movement, without the object being captured. This way a dynamically moving, watertight, and accurate homologous 4D mesh can be created of the actor.

**Keywords:** 4d scanning, markerless, cycling performance, Move4D

## 1. Introduction

In this white paper, the opportunities and current obstacles to using the Move 4D markerless motion tracking system (Instituto de Biomecánica de Valencia- IBV), for capturing human product interactions are discussed. Three-dimensional real-time motion tracking using marker-based systems is currently used to evaluate cyclists': 1) upper body positioning, 2) trunk stability, and 3) lower limb symmetry and kinematics [1,4]. However, MOVE4D's markerless photogrammetry-based 4D scanning system creates new opportunities and increased flexibility for cyclists' performance assessments. It consists of a set of 12 synchronized modules to scan full bodies with texture in motion [5]. One benefit is that it allows users to export each recorded frame as a homologous mesh. A homologous mesh refers to a finalized mesh where a standardized human body and the recorded participant's body are combined. The final mesh is watertight and retains high accuracy of the recorded actor's body [6]. In addition, it allows analysis of cyclists' posture and biomechanics through the placement of standardized digital trackers on the subject's digital body. These digital trackers can be used to determine trunk stability and symmetry in leg movement without requiring hand placement of markers that are susceptible to faults such as placement position errors, low battery while recording, and falling off the skin. Secondly, it could lay the technological basis to extend current CFD (computational fluid dynamics) analyses, with flow simulations executed with a dynamically moving, three-dimensional body and bicycle based on 3D meshes captured at 180 fps with a resolution of 2 mm [5]. Lastly, the flexibility of a markerless 4D scanning system allows motion tracking between any two points in the 3D mesh. While a marker-based motion capture system is limited to tracking between markers. Preliminary assessments of the system's ability to record cyclists and export them as a homologous model have shown the main issues with the current setup. These findings are shown in 3.1: assessment of current obstacles. It shows that currently

* "Alexander Van Gastel" Alexander.VanGastel@uantwerpen.be
** "Stijn Verwulgen" stijn.verwulgen@uantwerpen.be

recording humans while holding or using an object e.g. a bicycle, does not provide a usable homologous mesh. Exporting the capture as a homologous mesh will combine the object and the human body, as the system cannot discern it from the human body. This study provides one solution by coating objects used in the human-product interaction with a material that does not emit infrared (IR) in specific broadbands. This way the system will not generate point cloud data of the objects used in these interactions. Two IR and one visible light camera in each module capture IR and visible light emitted or reflected from surfaces to generate 3D geometry and colored textures. The major obstacle to defeating the IR cameras is to conceal the spontaneous emission of objects over a broadband IR spectrum, most importantly two transmission windows of 3–5 μm and 8–14 μm, within which the IR radiation easily passes through the atmosphere [7]. Coating objects with materials whose IR radiation properties are outside these transmission windows should make these objects invisible to the MOVE4D systems' cameras. Therefore, the cyclist's movement can be captured and exported as a homologous model, as the object is not captured by the cameras. The disadvantage is mainly related to CFD analysis, where the bicycle and helmet need to be added to a modeling software before being used for aerodynamic simulation.

# 2. Method

## 2.2. Assessment of current obstacles

The first exploratory observation was performed to assess current obstacles in the system's ability to provide a watertight and accurate mesh of both a bicycle and cyclist. One actor, a professional time trial rider (male, age: 24, weight: 69 kg, height: 185,5 cm), was captured during three sessions using the MOVE4D system, cycling at a constant speed on a time trial bicycle installed on a Wahoo KICKR trainer (Wahoo, Atlanta, USA). Recordings were exported as both homologous and normal meshes. Afterward, both mesh type's quality and overall benefits and disadvantages were assessed regarding cycling analysis.

## 2.3. Testing coatings that avoid IR camera detection

In the second exploratory observation, seven equal-sized PVC panels measuring 18x11 mm were coated in various materials, as shown in Table 1. The panels were held up in front of the researcher's upper body while the system's camera's recorded the scene. The objective of this observation is to determine which coating can beat the IR cameras by not emitting IR in the specified broadbands. The results are evaluated based on the ability or inability to capture the PVC-coated panels. Each recording was repeated and included four frames at the highest resolution setting.

## 2.5. Scanning using a tool with infrared absorbent coating

In the third and final experimental observation, a tool used by maritime workers was coated with product nr.3 (shiny black, Dupli-Color, 693854). This coating was able to make the PVC panel invisible to the IR cameras in the previous exploratory observation. One actor (male, age: 25, weight: 72 kg, height: 168 cm) carrying the coated tool, performed a series of movements. The recording was captured at 3 fps over 6 seconds, totaling 19 frames for evaluation based on: the number of gaps and accuracy in comparison to the real-world scene. Afterward, the frames were exported as homologous mesh and their quality was assessed based on the number of gaps in the mesh and if the human body is morphed unnaturally due to the system's inability to separate objects from the full human body.

# 3. Results

## 3.1. Assessment of current obstacles

*Table 1 Summary of advantages and disadvantages of normal and homologous mesh.*

| | Advantage | Disadvantage |
|---|---|---|
| Normal Mesh | • External objects can be captured without them being morphed | • A large amount of gaps in the model need to be filled manually. |
| Homologous mesh | • Gaps in the raw data are filled using a standardized human body (watertight model)<br>• Standardized digital markers | • Objects that interact with the human body become an extension, morphed into the human body. |

Results of the first exploratory study with a professional time trail rider have led to the following observations: 1) recording humans while holding or using an object e.g. a bicycle, does not provide a usable homologous mesh. Exporting the capture as a homologous mesh will combine the object and the human body as the system cannot discern it from the human body, as shown in Figure 1. Exporting the capture as a normal mesh does not have this problem. It solely processes the point cloud data gathered from the cameras directed at the scene. Unlike the homologous mesh type, it does not aim to combine the captured human body with a standardized version of a human body to fill gaps and provide digital markers. 2) the system's IR cameras are unable to detect some material surfaces. This is visible in Figure 2 where the mesh is shown to be incomplete around the Wahoo Kickr, wheels, and helmet. Notably, the helmet shown in the homologous mesh was covered with a rubber swimming cap so the IR cameras could capture it. During the capture of the normal mesh, the helmet was used without the rubber swimming cap. Unfortunately, the helmet material was invisible to the IR cameras. 3) Small, thin, or very fast-moving parts such as wheel spokes turning at a high rpm are also incomplete or missing in the final normal mesh, and 4) In the normal mesh a camera blind spot occurs at the top surface of the helmet, where the mesh is not fully closed. The homologous mesh can close this gap automatically based on geometry from the standardized human model.

*Fig. 2. Homologous model of professional cyclist using the Move 4D system – images from left to right show how the bicycle is treated as an extension of the human body.*

*Fig. 2. Raw mesh of professional cyclist using the Move 4D system – images from left to right show the incompleteness of the model. The helmet is different than in Figure 1., here the participant was not wearing a helmet that the infrared camera's were able to capture.*

Regarding cycling performance and aerodynamic analysis, both normal and homologous mesh types have certain advantages and disadvantages, as shown in Table 2. Arguably most important is that the homologous mesh provides a watertight 3D model. A watertight 3D model is a requirement for CFD analysis used in aerodynamic simulations of cyclists. Some recordings might include hundreds of frames. In case the 3D mesh would contain gaps, each frame, which constitutes a 3D model, would need to be manually repaired before being used in a CFD simulation. This would take too much time while the model would not necessarily be representative of the real-world scenario, due to human intervention in the creation of the mesh. Lastly, using a homologous mesh provides the operator with standardized digital markers which can measure various physical parameters. Additionally, with digital markers placed on the patella, greater trochanter, anterior and posterior iliac crest, and acromion it could be expanded to analyze the stability and symmetry of knee, hip, pelvis 1 and 2, and shoulder movements [8].

### 3.2. Testing coatings that avoid IR camera detection

Results of the second exploratory observation are shown in table 4. Out of nine coatings, one (shiny black, Dupli-color, 693854) was able to beat the IR cameras. During the capture, the system was not able to generate data for the point cloud of this PVC-coated plate which the actor held in front of his torso. Notably, a dark shadow is created on the texture of the homologous model due to light being blocked for the visible light camera. Nevertheless, the quality of the color texture does not affect the application of the 3D mesh in cycling analysis. So this artifact can be disregarded. As shown in Figure 4, the right side image shows that the IR cameras can detect the PVC panel, and while the homologous model shows similar results as in Figure 3, it could lead to deformation in de homologous model when interacting with larger objects.

*Table 2. Resulting visibility or invisibility of nine coatings on PVC panels.*

| Nr. | Type | Full product description (color, product code) | Result: visible or invisible |
|---|---|---|---|
| 1 | Spray-Paint | Metallic grey, Motip, 302501 | Visible |
| 2 | Spray-Paint | Flat gray, Spectrum, 698587 | Visible |
| 3 | Spray-Paint | Shiny black, Dupli-color, 693854 | Invisible |
| 4 | Spray-Paint | Matte black, Sencys, 5247787 | Visible |
| 5 | Tape | Grey tape, TESSA, 4662 | Visible |
| 6 | Tape | Striped electrical tape, 00351933RG | Visible |
| 7 | Tape | Black electrical tape, 00351933RG | Visible |
| 8 | Tape | Brown electrical tape, 00351933RG | Visible |
| 9 | Spray-Paint | White paint, Dupli-color, 467004 | Visible |

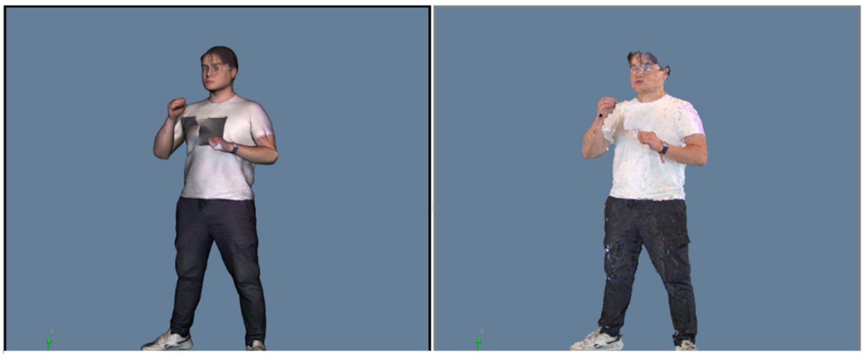

*Fig. 3. PVC panel coated in a coating that avoids detection by IR cameras - material nr.3 (Shiny black, Dupli-color, 693854). Right shows raw data, left shows resulting homologous mesh.*

*Fig. 4. PVC panel coated in a material that is detected by the IR cameras - nr.2 (Flat gray, Spectrum, 698587). Right shows raw data, left shows resulting homologous mesh.*

### 3.3. Scanning maritime worker using a tool with infrared absorbent coating

The final homologous model of the full human body shows no deformation around the wrist and hand area, which would normally be caused by the object used in the human product interaction. As shown in Figures 5 and 6, the participant holds an aluminum bar, coated in Shiny black, Dupli-color, 693854 which was established to not emit IR in the specified broadbands. Notably, a metal structure was placed in front of the actor to help achieve the same movement used in container lashing. This metal structure however did not affect the homologous mesh, also likely due to low IR emittance in the specific broadbands.

*Fig. 5. Maritime worker recorded using a container lashing tool coated in shiny black, Dupli-color, 693854. Left shows a watertight and accurate homologous model of the human body. Right shows the raw data from one frame of the capture.*

*Fig. 6. Scene of the recording that was captured in this observation.*

## 5. Conclusion

The homologous export function, compared to a normal mesh is chosen as the superior export type for cycling analysis. It can provide watertight meshes that could be used for CFD analysis performed with dynamically moving 3D meshes, which could improve accuracy toward real-world aerodynamics. Furthermore, the standardized or custom digital markers that are enabled by the homologous model allow quick physical assessments. Nevertheless, the system should be adapted to track joint and posture movement for biomechanical assessment. This study found that the human-product interaction poses the main obstacle to capturing cyclists on the MOVE4D platform and successfully using the homologous model. The proposed solution of making the product invisible for IR cameras through a coating that does not emit IR in the specified broadband of 3–5 μm and 8–14 μm was verified. The final exploratory observation shows a practical application, where a product-human interaction was performed and captured, and successfully exported as a homologous model, which is watertight and accurate. Similarly a bike and bike trainer could be coated in shiny black, Dupli-color, 693854. The homologous model can then be used as is for biomechanical analysis of the cyclist movement. However, for a dynamically moving CFD analyses, a 3D model of the bicycle should be made or 3D scanned and added to the homologous mesh.

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