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N. Pelechano and J. Pettré (Editors)

Overcoming Challenges of Cycling Motion Capturing and Building a Comprehensive Dataset

P.Kyriakou[1,3], M.Kyriakou[1,3] , Y.Chrysanthou[1,2]

[1]CYENS Centre of Excellence, Nicosia, Cyprus
[2]University of Cyprus, Nicosia, Cyprus
[3]Mirror 3D Lab, Paphos, Cyprus

Abstract

This article describes a methodology for capturing cyclist motion using motion capture (mocap) hardware. It also details the creation of a comprehensive dataset that will be publicly available. The methodology involves a modular system, and an innovative marker placement. The resulting dataset is utilized to create 3D visualizations and diverse data representations, shared in an online library for public access and collaborative research.

CCS Concepts

• ***Computing methodologies*** $\rightarrow$ ***Motion capture;***

1. Introduction

Cycling has evolved beyond a recreational activity into a highly competitive and scientifically-driven sport. Athletes and researchers alike seek to unlock the secrets of optimal cycling performance, biomechanics, and training strategies [MVD23]. The efficacy of pedaling, concerning both performance and anatomical correctness, is predominantly influenced by the angles formed between the joint segments. These kinematic variables, crucial for optimal pedaling, can be affected by modifications in pedaling speed, adjustments in body posture, and changes in the positioning of key bicycle components [LLA20]. Capturing the movements of cyclists requires a unique approach due to the dynamic nature of the sport [GMVGLVE24]. This article delves into the difficulties faced, the methodologies developed to overcome them, and the outcomes aimed at advancing research in cycling dynamics. The raw motion capture data are provided on an online library, available for research purposes, such as biomechanic analysis in relation with power, position and cadence.

2. Motion Capturing of Cyclists

Motion capture (mocap) is a cutting-edge technological process utilized to acquire three-dimensional (3D) positioning and orientation information of a moving object or person. Its exceptional precision in capturing and portraying movements has led to its widespread applications in various fields, such as entertainment, media, military, sports, rehabilitation, medical sciences and cultural heritage [AWSA].

The system used is the state-of-the-art Phasespace Impulse X2E motion capture system, featuring active LEDs. This system uses 24 cameras designed for capturing 3D motion through modulated LEDs. These cameras incorporate pairs of linear scanner arrays operating at high frequencies, enabling the capture of the position of bright spots of light generated by the LEDs. Notably, the system boasts a rapid capture rate of up to 960Hz, facilitating the identification of individual markers by synthesizing information from multiple frames. This process allows for the unique modulation of each marker to be discerned accurately. This system can capture 3D motion data over time for a single character or more, preserving accurate human proportions and the natural fluidity of actions, all while ensuring realistic motion [SAS*12].

However, cycling motion capture presents unique considerations due to the dynamic nature of the sport. Here, we explore key factors and the solutions we implemented to address them.

2.1. Cyclist Comfort: A Modular Solution

Cycling demands intense effort, elevating heart rates and causing significant perspiration. Traditional motion capture full-body suits were inadequate for this purpose. We designed a modular system with 3D printed cases (figure 1) to address comfort concerns. These cases, accommodating 2 or 4 LEDs per module, prioritize breathability, ensuring cyclist comfort during vigorous exercise.

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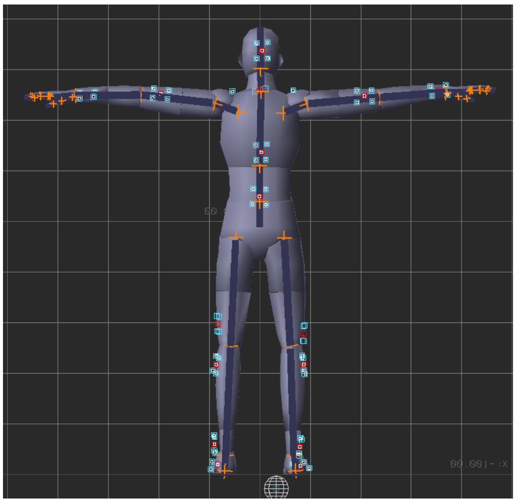
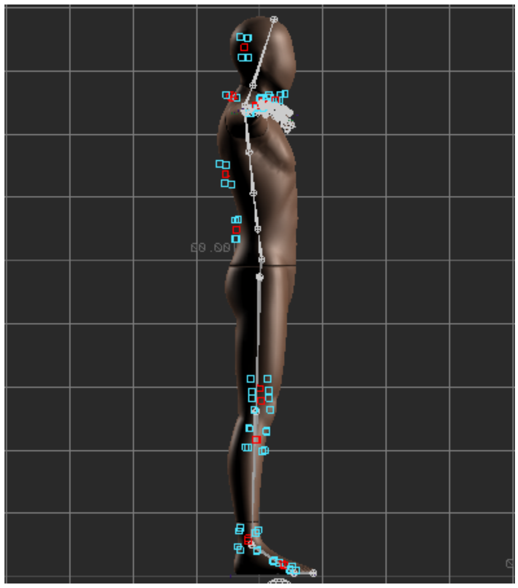


Markers are placed mostly on the back using a modular system featuring 3D printer cases.

Figure 1: *Back view of cyclist with modular markers placement.Light blue squares are the markers placement, and red squares are the rigid bodies created from groups of markers.*



Markers were strategically put mostly on the back side of the torso due to the body position while cycling.

Figure 2: *Side view of marker positions*

2.2. Unique Marker Placement

Traditional marker placement faced obsolescence due to the cyclist's inclined posture. Placing markers on the front became impractical, leading to a novel approach. All markers were strategically positioned on the side and back (figure 2), circumventing the problems associated with marker occlusion during cycling positions. One set of 4 markers were set on the back of the head. The next of 4 markers, was distributed like this: 2 on the top back (1st thoracic vertebrae), and one marker on each shoulder (acromiom). Next 2 sets of 4 markers were placed on the middle of the back (6-7th thoracic vertebrae) and lower back (1st-2nd lumbar vertebrae). Then on each arm we had a set of 4 markers just above the elbow, and one set of 4 markers at the wrist. On each leg we had 4 sets of 4 markers: One above and one below the knee, one above the ankle and last ser on the top of the shoe. The 64 (active) markers were connected to 8 micro-controllers.

Cycling involves vigorous knee movements, particularly at high cadences, which is why very common that it is a commonly reported problem area for cyclists [Cal05]. To ensure precision in capturing motion without compromising cyclist safety and comfort, joint markers, especially those on the knees, were intentionally avoided.

3. Methodology for Mocap Data Collection

Participants received detailed information about the mocap data collection procedure and purpose. Informed consent was obtained, ensuring understanding and agreement and a pre-session questionnaire collected demographic and health information. Next, the participant's road or time trial (TT) bike was placed on a turbo trainer and the careful marker placement on the cyclist's body as described in Section 2.

Cyclists followed a specific workout plan based on their bike type. The plan included warm-up, cycling positions, and recovery intervals.

Workout:
- Warm-Up: 1 minute in any position.
- 30 seconds at 60 RPM
- 15 seconds at 75 RPM
- 15 seconds at 90 RPM
- 10 seconds at 100 RPM
- 10 seconds at 110 RPM

Cycling Positions and Cadences

For Road Bikes:
The workout was performed for each of the following positions with 1 minute between each position to allow for recuperation:
- Straight Arms
- Comfortable
- Aggressive
- Aero Position
- Standing (not above 90 RPM)

For TT Bikes:
The workout was performed for each of the following positions with 1 minute between each position to allow for recuperation:
- Comfortable
- Aero Position
- Standing (not above 90 RPM)

Participants were monitored throughout the session to ensure well-being and comfort. They had the option to terminate the procedure if they feel unwell or wish to stop.

4. Building a Comprehensive Dataset

The proposed solution applied in motion capturing cyclists, coupled with the staight-forward methodology, result in a comprehensive dataset. Even though this is not the first time that cyclist are recorded in motion capturing labs [WBGC23, JHsY*23, SES*21], there are not freely available data for researchers that do not have access to expensive motion capture labs. This dataset serves as a valuable resource for further analysis, simulations, and research in the realm of cycling dynamics [HFTS17], such as bio-mechanic analysis in relation with power, position and cadence [MGSS07, BH23, TW20, BC17].

Data recorded include the motion capture system records from PhaseSpace system as well as data about power produced from the participants, recorded in FIT files format by a virtual cycling application (zwift.com) and will be available in the dataset.

4.1. BVH Library

In addition to the raw data, our dataset includes processed BVH files. This section outlines the process of constructing the BVH library, addresses encountered challenges, and provides insight into the library's structure and organization.

Data Processing

Initially, the raw mocap data, consisting of marker positions and skeletal movement, were imported into Autodesk MotionBuilder—a specialized software designed for mocap data processing. In MotionBuilder, the data underwent cleaning and pre-processing. This involved removing any noise or outliers in the marker data to enhance accuracy. Each marker from the motion capture system was assigned to a specific virtual body part, so that the data accurately represented the movements of individual body segments.

The next step involved mapping the markers to a skeleton of an avatar, aligning the markers with the corresponding joints and bones. Once the markers were properly mapped, the data were exported in the BVH file format. BVH is particularly suitable for encoding skeletal motion data, making it an ideal choice for representing the cyclist's movements. Naming and Organization: The BVH files were named and organized to facilitate easy retrieval and utilization in subsequent project tasks.

Some of the problems that were face in the data processing phase include:

- Data Noise: Some mocap data contained minor inconsistencies and noise, which required careful cleaning and preprocessing. This was addressed through data filtering and outlier removal techniques.
- Marker Occlusion: Instances of marker occlusion, where markers were temporarily obstructed from view, posed difficulties in tracking. To mitigate this, redundant markers and alternative tracking methods were employed.
- Data Synchronization: Ensuring synchronization between the markers and the avatar's skeleton was essential for accurate representation. Close attention to marker-to-skeleton mapping was the key to overcoming this challenge.

Figure 3: *Straight-Arms Position - On Road Bike.*

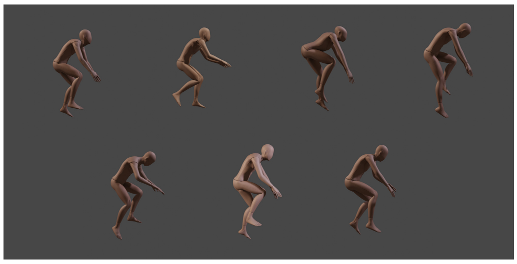


Figure 4: *Comfortable Position - On Road Bike.*

Figure 5: *Aggressive Position - On Road Bike.*

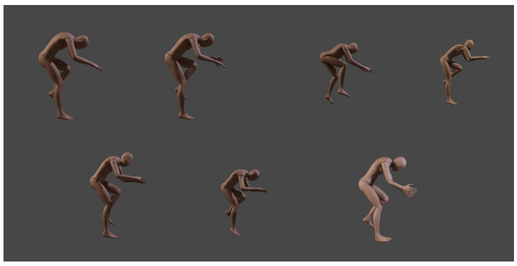


Figure 6: *Aero Position - On Road Bike.*

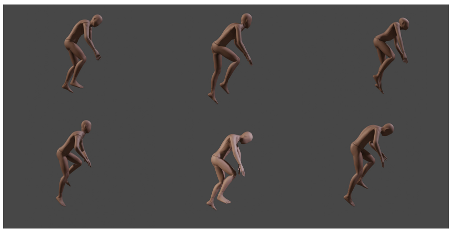


Figure 7: *Standing Position - On Road Bike.*

Figure 8: *Comfortable - On TT Bike.*

Figure 9: *Aero Position - On TT Bike.*

Figure 10: *Standing Position - On TT Bike.*

In summary, the BVH library was created from raw mocap data, ensuring data quality and synchronization for further analysis and visualization (figures 3-10). The library is well-organized for ease of use.

5. Results and Data Overview

This section offers an overview of the collected motion data, summarizing the key characteristics of the dataset obtained from 11 cyclists, including details about participant demographics and recording sessions.

5.1. Overview of Collected Motion Data

- Participant Demographics: The dataset comprises 11 participants, including 10 male cyclists and 1 female cyclist. This set of data could be extended with more female participants.
- Bike Types: The participants utilized a total of 7 road bikes and 4 time trial (TT) bikes during the data collection sessions. This diversity in bike types adds variability to the dataset and allows for a comprehensive analysis of different cycling scenarios.
- Recording Sessions: Each recording session lasted approximately 12 minutes. This duration provides a substantial dataset for various cycling positions, ensuring adequate data for use in subsequent analyses and simulations.

5.2. Key Statistics and Metrics

The dataset collected from these recording sessions includes a wealth of information that can be leveraged for in-depth analysis and simulations. Key statistics and metrics related to the dataset include:

- Cycling Positions: The dataset encompasses various cycling positions, including but not limited to straight arms, comfortable, aggressive, aero position, and standing for road bikes, and comfortable, aero position, and standing for TT bikes.
- Marker Data: Detailed marker data capture the precise movements of cyclists during their sessions, enabling the analysis of joint angles, body posture, and motion dynamics.
- Skeletal Data: The skeleton data, mapped onto avatars, provides insight into how different body segments interact and move during cycling, offering valuable information for bio-mechanical analysis.
- Cyclist-Specific Variations: Variations in cyclist characteristics, such as body morphology, pedaling technique, and fitness level, contribute to the richness of the dataset and allow for the exploration of individualized cycling dynamics.

This dataset is poised to serve as a first step to create a valuable resource for advanced analyses, simulations, and visualizations, which can facilitate research into optimal cycling performance, training techniques, and bio-mechanical insights.

The collected motion data not only represents the motions of 11 cyclists but also forms the foundation for the subsequent creation of 3D visualizations and data representation templates.

Dataset Structure

The motion capture dataset is organized as follows:

There is a dedicated folder for each participant, labeled according to the following naming convention:

"1_RB_M42_20230719_PK"

- 1 = Index Number
- RB = Road Bike (RB) or Time Trial bike (TT)
- M42 = Gender (M/F) and age
- 20230719 = Capture Date (YYYYMMDD)
- PK = Unique Identifier of participant

In each folder there are three files:

- C3D = Motion Capture Raw Data
- BVH = BioVision Hierarchy (BVH), data mapped to skeletal data ready for animation (errors may still remain)
- GPX = Data from related zwift workout

6. Conclusion

The presented methodology not only addresses the challenges of motion capturing cyclists but also paves the way for a new era of collaborative research in cycling dynamics. By sharing the dataset and visualizations through an online library, we invite the global research community to explore, analyze, and contribute to the evolving landscape of cycling science.

7. Data Availability Statement

All data is available on Zenodo [KCK24] .

8. Acknowledgments

We extend our gratitude to all contributors, partners, and researchers who have played a role in advancing our understanding of cycling dynamics. Special thanks to the participants whose dedication made this research possible.

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10. Future Directions

As we continue our journey in advancing cycling science, future directions include refining our motion capture methodology, expanding the dataset, and exploring new avenues for analysis. We welcome collaborations and contributions from the scientific community to further enhance the richness of this dataset and its applications.

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