# Analysis of sword fencing training evaluation possibilities using Motion Capture techniques


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***Abstract*—Inspired by works that included the use of Motion Capture for human body movement estimation, authors have created a program to test the correct performance of sword fencing in terms of combat sports, more specifically, the Historical European Martial Arts (HEMA). The focus is on the analysis of four actors, only one of them is a professional fencer. Each made the same motions that were recorded by the MoCap system to determine the pattern of the correct cut and show the mistakes made by amateurs.**



***Index Terms*—sword fencing, fencer, motion capture, human body movement estimation**


## I. Introduction

Sport has accompanied mankind for thousands of years, allowing us to discharge emotions and to use natural competitive needs in a good way. Therefore, in each discipline, there is a way of evaluating the techniques performed, in order to select the best player from among the competition. However, in many of the disciplines, such as martial arts or dancing, a subjective score is given by a human referee, which can lead to fraud or unfair results. In the following work, we will show how to eliminate this factor using the technology of Motion-Capture on the example of Historical European Martial Arts (HEMA).

## II. Methods and Materials

### A. Literature review

The article by Noiumkar et al. [1] presents the way of recording and processing a golf impact into an animation using optical Motion Capture. The way of registering the data and body parts that the authors have paid attention is following a similar scheme as for sword strikes. In order to capture the movement, the scientists divided the data collection into two stages. In the first stage, they focused on creating a 3D animation using the data collected during the recordings, in the second stage they assessed the conformity and correctness of the recordings and animations with the 5 scale questionnaire under the supervision of a golfing expert.

A similar subject matter is covered by the works of Cha et al. [2] inspired by the need for effective training materials of beginner mountain climbers. This research aimed to analyze the attitude and movement of a professional climber to identify the correct postures. The climbing cycle was divided into 4 phases and each of them was analyzed. With two Kinects and iPi Recorder, the authors recorded depth data and RGB videos. The depth data was processed via iPi Mocap Studio to establish a three-dimensional vine skeleton, which was processed, exported and analyzed with public domain software.

Weichen et al. [3] have introduced a new data set, Martial Arts, Dance and Sport (MADS), which includes sports actions such as tennis, basketball or volleyball; dance actions or martial arts to estimate human position. The recordings were made with the use of multiple cameras and a deep-sea stereo camera. Through the use of various tracking frames, authors were able to provide preliminary baseline results.

With the use of Microsoft Kinect, Nisfu et al. [4] have developed a combat training system application built based on traffic registration. The process of the movement is made from application analysis requirement to capture user's movement, showing depth stream views and 3-dimensional animation. The implementation process based on movement recording is made based on the application requirement. This method helped to tag the movement's name in the movement's recording file. In the implementation of gesture matching, there is a replay function, matching movement and the calculation results of the exercise.

The description of the use of Motion-Capture data recorded during the dance can be found in the article by Chan et al. [5]. It's a training system with immediate feedback on the accuracy of the movement. The movement was recorded using an optical Mocap system which, according to the authors, ensures the shortest response time and the highest accuracy of measurements. The data is presented to the user, on the screen, in the form of cylinders representing specific body parts (the limbs that do not follow the movement of the model are highlighted in red). At the end of the session, the program displays a report on the accuracy of movements of each limb during the dance training.

Another work by Sobel et al. [6] presents an idea of Motion-Capture data registration and use in medical applications. The authors used cameras and markers to record the patient's movements to calculate the values of angles occurring in selected limbs during the exercise. The ready-made functions of the OpenCV library were used to display reference lines and angle values. The equations allowing for the reduction of the camera distortion were also described, and are used to increase the accuracy of the calculations (ultimately, 0.1-micrometer accuracy was achieved).

The example by Phunsa et al. [7] is a presentation of movement data captured to animate two 3D models of Thai martial arts warriors. The authors recorded over 30 self-defense techniques performed by two experts in Thai boxing. The recordings were made using 9 optical motion capture cameras and 42 markers (21 on each actor). After cleaning the data, animations were successfully imported to the models.

### B. Historical European Martial Arts

For this research analyzed movements are restricted to a single discipline - Historical European Martial Arts (HEMA), longsword fencing which has been experiencing a rising popularity since the 1990s. HEMA focuses mostly on reenacting fighting styles of Late Middle Ages and Renaissance, with a few exceptions like military saber fencing being based on XVIII and XIX books. The main reason for this is a lack of complete documentation for earlier periods, and without proper treatises, it is more of a guesswork than a proper reenactment.

## III. Current Platform

### A. Sortware framework

Recordings and calibrations were made using 8 OptiTrack Flex 13 cameras connected according to the scheme 1, a calibration triangle, a calibration wand, passive reflective markers in numbers: 41 on an actor and 5 on the prop sword. Software used during recording and data processing: OptiTrack Motive v.1.0. and Autodesk Motion Builder. Motive software provides Motion Capture data export to five different formats: CSV, C3D, FBX, BVH and TRC. More on each of the formats can be found in the manufacturer's documentation. [8]. For

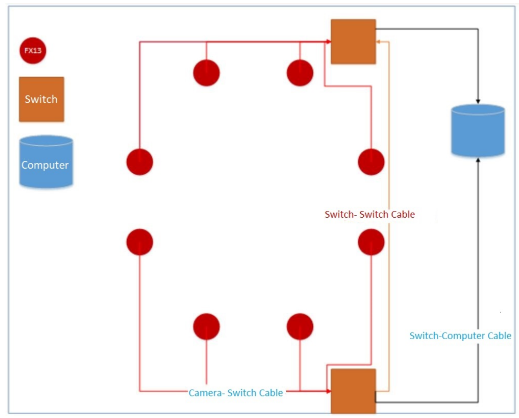


Fig. 1. Camera connection diagram.

the purpose of work the .C3D format was chosen because it is compatible with the *pyomeca* library used in the program. This is a binary file format used for exporting and exchanging raw motion capture data. It is particularly used in biomechanics and motion studies [8]. In the .C3D format, each information frame is represented as a list comprising Cartesian coordinates (x, y, z) in 3D space for each marker [9]. Coordinates of markers moving in time are recorded. Thanks to this data it is possible to assign markers and their coordinates to the skeleton and then to the animated character. It also allows synchronization and storage of additional data streams together with MoCap data [10].

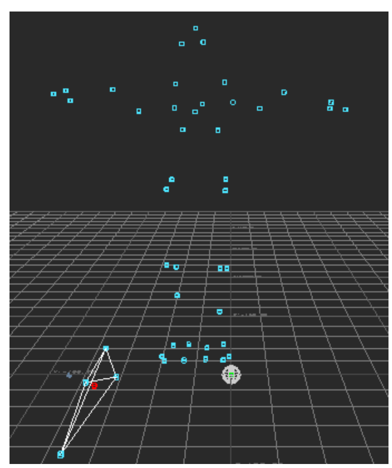

Fig. 2. Actor's starting position (.C3D format), preview in Motion Builder.

### B. Data Acquisition

A pattern that was analyzed is a set of 5 different Meisterhau's (master cuts):

- Zornhau – Diagonal strike from the top. Called an "Wrath strike" because, according to Liechtenauer [11] an angry fencer wielding a sword instinctually will use this technique.

- Krumphau – Strike from the top aiming to him the wrists or sword of the opponent. Usually while performing this technique fencer will step to the side, out of the enemy's sword trajectory.
- Zwerchhau - High, horizontal cut aiming to the head, if performed correctly, at the same time deflecting the opponent's strike.
- Schielhau – Strike performed with the false edge (the one that at the beginning of the move is facing the performing fencer). Moves opponent's sword to the side simultaneously hitting him in the arm.
- Scheitelhau – Vertical strike to the head using only the tip of the sword, usually performed with a step back.

[11]–[13]. The basis of these cuts is simple: when you are being attacked, you should counter your enemy in the same time by deflecting his strike while still hitting him within the same move. Movements of trained fencer and three different actors were captured while performing these cuts. Three different actors (two of which were untrained and were just instructed a few moments before records) were capture. Actors tried to mimic strikes (minimum of 2 different takes per actor per strike, depending on the quality of the recording). The captured movement was then exported to a c3d format and analyzed. This includes pasting the trajectories from other markers to solve swapping problem and interpolating the gaps in data when occlusion occured.

### C. Developed application

The software was created using Python and the following liblaries: *numpy, itertools, ezc3d,* and *pyomeca*. In order to compare the Euclidean distances obtained, the data were normalized. The length of each actor's arm was divided by the length of the sword. In this way the coefficients contained in the Table I were obtained. The normalization process consisted of dividing euclidean distances by the achieved coefficients. The recorded trajectories of the actors are compared to the base model, depending on the selected markers. Base model was an actor, whose movements - thanks to his specialized training and knowledge in the discipline could be interpreted as a reference to a non-trained actor. Each movement is presented in three axes. This allows us to observe the differences in movement of individual actors. The program needed a different approach, because of being out of phase of axis and a poor similarity score while using Euclidean distance between the i-th points of the trajectories compared. The algorithm implemented in software is Dynamic Time Warping, which is mainly used for speech recognition [14]. To run, the program needs a path to files in c3d format and the names of the markers which are about to be compared. The same names are automatically assigned to markers in different files (e.g., Phantom_1-Hips_1) with an exception for a sword prop. Because of differences in determining a rigid body during recordings, the markers are sometimes differently numerated (tip of the sword-in the base model it is called Rigid_Body_1-Marker_5 but in other recordings it is Rigid_Body_1-Marker_3). The algorithm computes the warping function using two time-series and draws the best alignment path (also called the warping path).

TABLE I
NORMALIZATION TABLE

| Actor | Arm length[cm] | Sword length [cm] | Factor |
|---|---|---|---|
| Base model | 67,95 | 119,89 | 0,5 |
| Experienced fencer | 57,5 | | 0,48 |
| New fencer 1 | 51,18 | | 0,43 |
| New fencer 2 | 60,86 | | 0,51 |

## IV. THE RESULTS

Three of the five master cuts were analysed: Schielhau, Zornhau, Zwerhau. To evaluate the validity of the movements, a marker situated at the upper end of the sword was used. This trajectory was measured because of the whole motion of the attack is useless if the strike goes wide even without the opponent and usually the contact with the target is made either with the tip of the sword or a point close to it. After checking if the attack was performed successfully other trajectories of other markers were similarly processed but for the sake of brevity only graphs representing the movement of the marker on the tip of the swords were presented. The graphs (Fig.3-11) compare the position of the marker in a standardized coordinate system. This allows to observe the differences in sword movement by actors in three separate Cartesian axes. On some axes the results are comparable, but it cannot be deduced that an experienced swordsman performed best compared to the base model. For example, in Figure 7. we can see that Y trajectory of the base model and an experienced fencer is similar in shape although the latter is slower, it takes more time to complete. The new fencer 2 is in a similar position to an experienced fencer but the new fencer 1's movement is completely off and doesn't resemble the movement it should. The same situation occurs with the Dynamic Time Warping algorithm, which uses the Euclidean measurement. DTW is an algorithm used mostly for measuring similarity between two different time series which may be out of sync in timing [15]. In this case we find the path of the best alignment of the two graphs and then measure the normalized distance between two trajectories [16]. The diagrams for Zornhau cuts for an experienced swordsman are presented (Fig.12-14). Figures show a warping path between a model and an experienced fencer. It shows which samples in the time series of the analyzed movement have been aligned to which samples of a chosen base model. The corresponding points were chosen in a way that minimizes the cost of matching two movements (the model and analyzed fencer). The total cost of matching the movements is a sum of all the local distances between the aligned samples deviates from the desired position. From the graphs obtained it can be concluded that the point selected for analysis was not sufficient. The next step will be to analyze all available points obtained by recording the Mocap, in order to select the best possible model to compare movements.

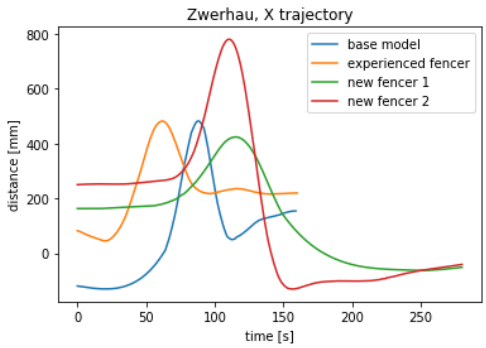


Fig. 3. X Trajectories of sword tip marker, Zwerhau move.

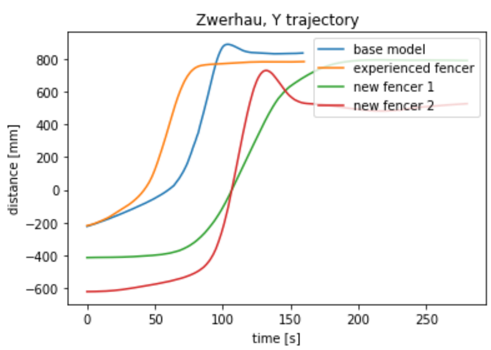


Fig. 4. Y Trajectories of sword tip marker, Zwerhau move.

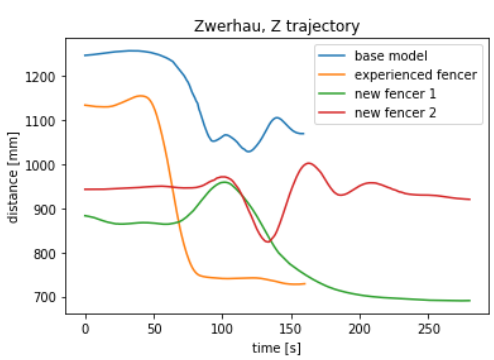


Fig. 5. Z Trajectories of sword tip marker, Zwerhau move.

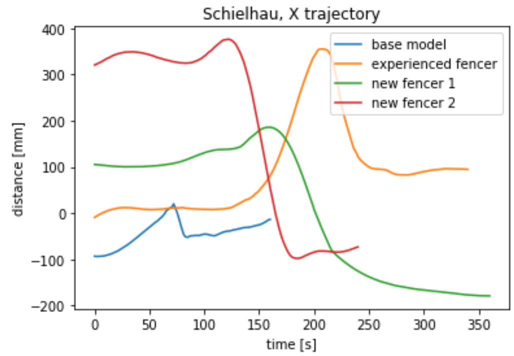


Fig. 6. X Trajectories of sword tip marker, Schielhau move.

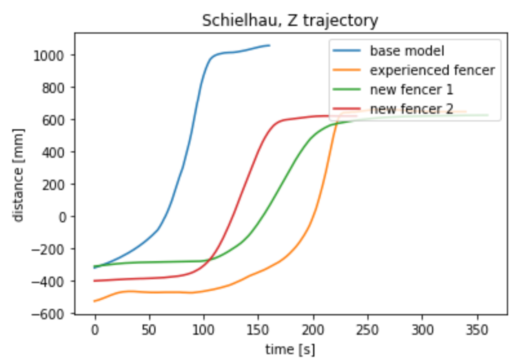


Fig. 7. Z Trajectories of sword tip marker, Schielhau move.

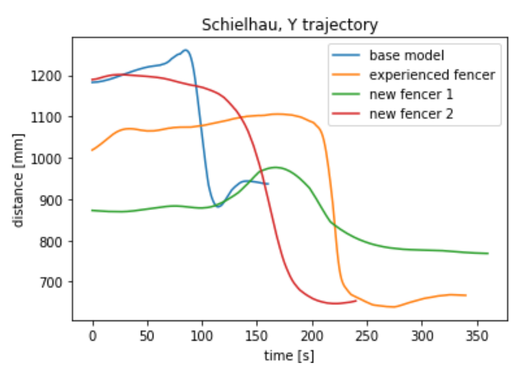


Fig. 8. Y Trajectories of sword tip marker, Schielhau move.

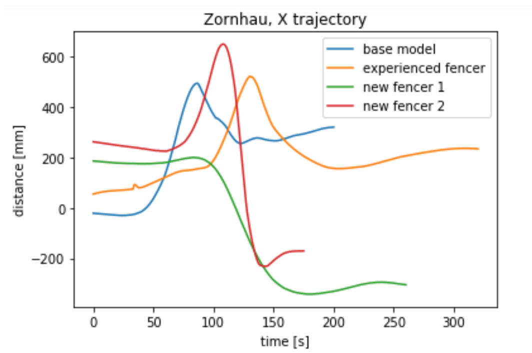


Fig. 9. X Trajectories of sword tip marker, Zornhau move.

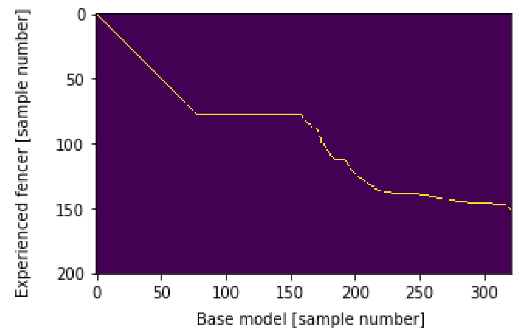


Fig. 12. Warp path od the X trajectory, experienced fencer, Zornhau move.

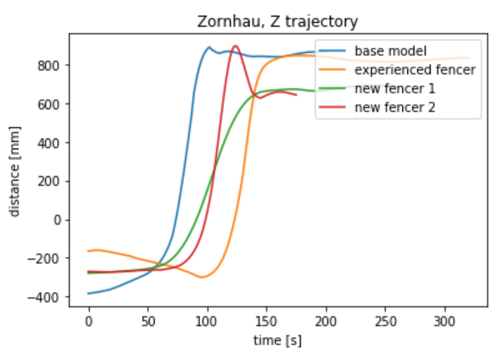


Fig. 10. Z Trajectories of sword tip marker, Zornhau move.

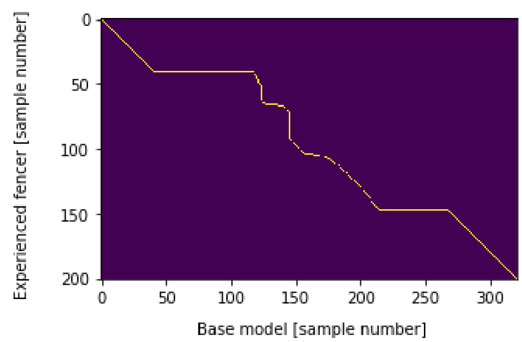


Fig. 13. Warp path od the Z trajectory, experienced fencer, Zornhau move.

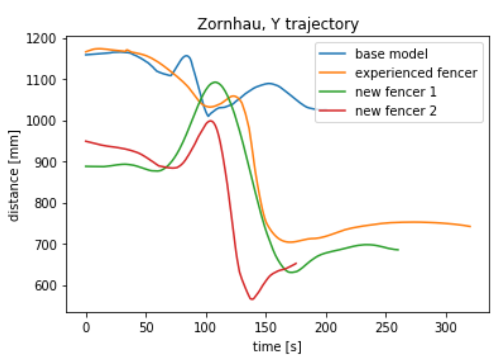


Fig. 11. Y Trajectories of sword tip marker, Zornhau move.

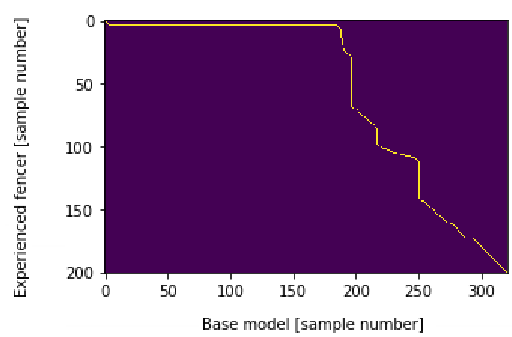


Fig. 14. Warp path od the Y trajectory, experienced fencer, Zornhau move.

## V. CONCLUSION AND DISCUSSION

In this research, the authors obtained motion capture data and analyzed the pattern of the correct cut, which they compared with the movements of fencing amateurs. The results were analyzed and a way to improve the algorithm was proposed.

Besides these required changes in the programme to increase the number of markers under examination, other improvements are planned. The application will be further developed to improve the usage of it during the training. Firstly there will be added a method measuring the speed of the movement because even a correctly performed movement is useless in a fight if performed too slow (and it was observed issue while recording the new fencers for this study). It is also planned to implement analyzing few markers located close to each other (for example 4 markers on one foot). Due to the fact that the distance between those markers can't change because they are located on one part of the body with no joints in between it will be possible to discern which of the trajectories of these markers is captured the worst and discard it for the purposes of the analysis. It could help to negate the need for filtering the data the way it is done currently and maybe even enable a close to real-time feedback for the performer. Another way to improve the proposed approach could be using the video tag system [17]. It is possible to use tags in 2D format [18]. This would provide an opportunity to speed up the analysis of mocap recordings, whose data are increasing in relation to the expansion of the area of motion research and the number of verified markers. This will allow for automatic motion data analysis with no need for individual simulations between recordings.

## REFERENCES


[1] S. Noiumkar, S. Tirakoat, Use of Optical Motion Capture in Sports Science: A Case Study of Golf Swing, 2013 International Conference on Informatics and Creative Multimedia, 2013

[2] K. Cha, E.Y. Lee, M.H. Heo, K.C. Shin, J. Son, D. Kim,, Analysis of Climbing Postures and Movements in Sport Climbing for Realistic 3D Climbing Animations. Procedia Engineering, 112, 52–57, 2015.

[3] W. Zhang, Z. Liu, L. Zhou, H. Leung, A. B. Chan, Martial Arts, Dancing and Sports dataset: a Challenging Stereo and Multi-View Dataset for 3D Human Pose Estimation, Image and Vision Computing, 2017.

[4] N. A. Sani, M. A. Hendrawan, F. Samopa "Development Of Basic Taekwondo Training System Application Based On Real Time Motion Capture Using Microsoft Kinect", The Third Information Systems International Conference, 2015.

[5] J. C. P. Chan, H. Leung, J. K. T. Tang and T. Komura, A Virtual Reality Dance Training System Using Motion Capture Technology, in IEEE Transactions on Learning Technologies, vol. 4, no. 2, pp. 187-195, April-June 2011.

[6] D. Sobel, J. Kwiatkowski, A. Ryt, M. Domzal, K. Jedrasiak, L. Janik, A. Nawrat, Range of Motion Measurements Using Motion Capture Data and Augmented Reality Visualisation. Lecture Notes in Computer Science, 594–601, 2014.

[7] S. Phunsa, N. Potisarn, S. Tirakoat, Edutainment - Thai Art of Self-Defense and Boxing by Motion Capture Technique. 2009 International Conference on Computer Modeling and Simulation, 2009.

[8] OptiTrack Documentation Wiki: https://v20.wiki.optitrack.com (last access 13.03.2020)

[9] C. Dobrian, F. Bevilacqua, Gestural Control of Music Using the Vicon 8 Motion Capture System. Proceedings of the 2003 Conference on New Interfaces for Musical Expression (NIME-03), Montreal, Canada, 2003.

[10] M. Müller, T. Röder, M. Clausen, B. Eberhardt, B. Krüger, A. Weber, Documentation Mocap Database HDM05. Computer Graphics Technical Reports CG-2007-2, 2007.

[11] J. Hartlieb, J. Liechtenauer, H. Talhoffer, "Talhoffer Fechtbuch (MS Chart.A.558)", 1448.

[12] J. Meyers, "Joachim Meyers Fäktbok (MS A.4º.2)," Lunds Universitets Bibliotek, 1560.

[13] P. von Danzig zum Ingolstadt, M. Huntfeltz, J. Liechtenauer, "Codex Danzig (Cod.44.A.8)," Accademia Nazionale dei Lincei, 1560.

[14] H. Sakoe and S. Chiba, Dynamic programming algorithm optimization for spoken word recognition, in IEEE Transactions on Acoustics, Speech, and Signal Processing, vol. 26, no. 1, pp. 43-49, 1978.

[15] A. Mueen, E. Keogh, Extracting Optimal Performance from Dynamic Time Warping. Proceedings of the 22nd ACM SIGKDD International Conference on Knowledge Discovery and Data Mining, pp. 2129-2130, 2016.

[16] T. Giorgino, Computing and Visualizing Dynamic Time Warping Alignments in R: The dtw Package. Journal of Statistical Software, 2009.

[17] S. Liu, F. Shao, Development of Intelligent Tag System. In 2019 12th International Congress on Image and Signal Processing, BioMedical Engineering and Informatics (CISP-BMEI) (pp. 1-6). IEEE, 2019.

[18] R. Klempous, K. Kluwak, J. Nikodem, M. Kulbacki, J. Segen, W. Knieć, A. Serester, Review of Algorithms for Tag Detection in Video Sequences. In 2018 IEEE 22nd International Conference on Intelligent Engineering Systems (INES), pp. 359-364, IEEE, 2018.