Niğde Ömer Halisdemir Üniversitesi
Spor Bilimleri Fakültesi
BEDEN EĞİTİMİ VE SPOR BİLİMLERİ DERGİSİ

İKİ BOYUTLU HAREKET ANALİZİNDE HAREKETLİ KAMERA APARATININ UYUM GEÇERLİĞİ: BİR YÜZME ÇALIŞMASI

THE CONCURRENT VALIDITY OF A MOVING CAMERA APPARATUS IN 2-DIMENSIONAL MOTION ANALYSIS: A SWIMMING STUDY

Gönderilen Tarih: 20/10/2020
Kabul Edilen Tarih: 16/02//2021

Uğur ÖDEK
Nevşehir Hacı Bektaş Veli Üniversitesi, Eğitim Fakültesi,
Beden Eğitimi ve Spor Bölümü, Nevşehir, Türkiye
Orcid: 0000-0003-0335-7956
Kürşat ÖZCAN
Nevşehir Hacı Bektaş Veli Üniversitesi, Eğitim Fakültesi,
Beden Eğitimi ve Spor Bölümü, Nevşehir, Türkiye
Orcid: 0000-0002-4463-1272

* Sorumlu Yazar: Uğur ÖDEK, Nevşehir Hacı Bektaş Veli Üniversitesi, E-mail: ugurodek@gmail.com

İki Boyutlu Hareket Analizinde Hareketli Kamera Aparatının Uyum Geçerliği: Bir Yüzme Çalışması

ÖZ

Bu çalışma, video tabanlı hareket analizlerinde kullanılmak üzere hareketli kamera aparatının yapımını açıklamakta ve serbest stil yüzmenin yatay hızı için sistemin geçerliğini rapor etmektedir. Çalışmaya dokuz erkek yüzücü (boy = 178.3 ± 6.3 cm, ağırlık = 82.6 ± 5.8 kg, yaş = 22.3 ± 3.86 yıl) katılmıştır. Yirmi metre serbest stil yüzme performansları hem hareketli kamera sistemi hem de sabit bir kamera kullanılarak kaydedilmiştir. Yüzücülerin bel bölgesine yerleştirilen bir işaretleyici yatay hızı hesaplamak amacıyla hareket analiz yazılımı kullanılarak takip edilmiştir. İki boyutlu hareket analizlerinin ardından iki sistemden elde edilen veriler incelenmiştir. Sabit kamera kayıtları kullanılarak hesaplanan yatay hızlar referans olarak kabul edilmiştir. Sonuçlar, hareketli kamera aparatı kullanılarak hesaplanan yatay hızların zaman serilerinin hiçbir noktasında referans değerlerden 0.05m/s'den fazla sapmadığını göstermiştir. Hoeffding'in D testi, 18 veri çiftinin anlamlı ölçüde birbirine bağımlı olduğunu (*p*<.05) ve veri serilerinin benzer eğriler çizdiğini ortaya koymuştur. Sonuç olarak geliştirilen aparatın hassasiyeti yüzmede kinematik analizlerin yapılmasına izin vermektedir ve sabit kamera sistemlerine alternatif olarak kullanılabilir.

Anahtar Kelimeler: Yüzme, Video, Hareket Analizi, Kinematik

The Concurrent Validity of a Moving Camera Apparatus in 2-Dimensional Motion Analysis: A Swimming Study

ABSTRACT

This study describes the building of a moving camera apparatus for use in video-based motion analysis and reports its validity in the horizontal velocity of freestyle swimming. Nine male swimmers (height = 178.3 ± 6.3cm, weight = 82.6 ± 5.8 kg, age = 22.3 ± 3.86 years) participated to the study. Twenty meters freestyle swimming performances were recorded using both a moving camera apparatus and a stationary camera. A marker placed on the lumbar region of the swimmers was tracked to calculate horizontal velocity. After 2D motion analyses, the data obtained by two different methods were investigated. Horizontal velocities calculated using stationary camera recordings were taken as reference. Results showed that the horizontal velocities calculated using the moving camera apparatus's recordings did not deviate from reference values more than 0.05 m/s at any point of the time series. Hoeffding's D measure test revealed significant dependencies for 18 data couples (*p*<.05) indicating data series draw a similar trajectory. In conclusion, the accuracy of the apparatus allows for kinematic analyses in swimming and the can be used as an alternative to stationary cameras

Key Words: Swimming, Video, Motion Analysis, Kinematics

INTRODUCTION

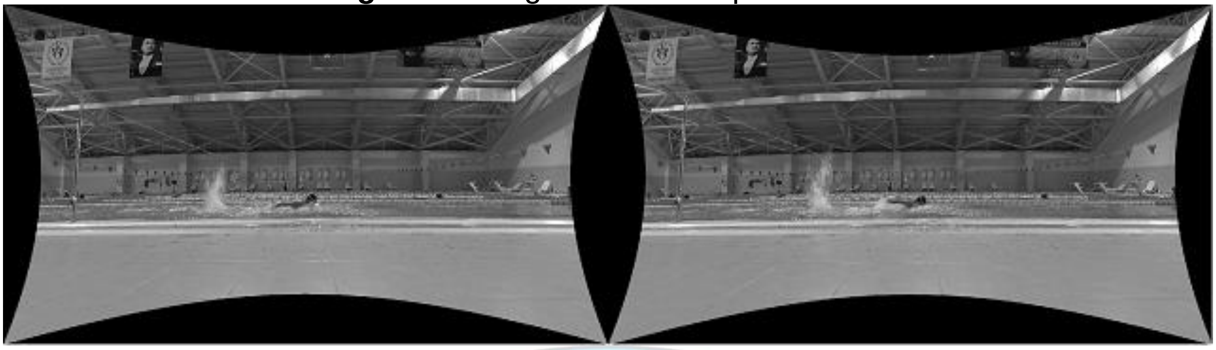
Biomechanical analyses provide essential information to researchers, coaches, and athletes in many sports branches. Although the primary purpose is to analyze the kinetics and kinematics, a wide variety of methods is used to collect data[1]. Video-based motion analysis is one of the oldest and still the most preferred method for two and three-dimensional kinematic analyses[2].

It is possible to come across two types of kinematic analysis studies commonly used in swimming. One of them is race analysis, frequently include temporary variables as the start, free swim, turn and finish times and variables related to stroke characteristics as stroke rate, stroke distance[3-4]. Even though race analyses give strong evidence about swimming performances, the information is not adequate to explore swimmers' techniques in detail. The primary cause for that is the distance between the camera/cameras and the swimmers[5] Therefore, another type of analysis called technical analysis is needed in which cameras are placed as close as possible to record swimmers' movements clearly. Using these close captured recordings, analysts can do further kinematic calculations of acceleration, angular changes, intra-cyclic velocities during propulsive and non-propulsive phases of the stroke etc.

Video-based motion analysis has some limitations, which are mostly related to equipment costs and workload[6,7]. For example, in 2D analyses in which the performance does not fit into a single camera's field of view, more than one camera is needed[2]. In that case, as well as the cost, the workload increases due to post-processing of the recordings and analyzing the images recorded by each camera. Lens distortion is another problem that increases when multiple camera systems are used[8]. Some software-based techniques are developed to minimize lens distortion digitally. However, there is a trade-off. After correction, images are reshaped, and indentations occur at the edges that break the continuum of the images obtained by lined up cameras (Figure 1).

Because of the difficulties mentioned above, researchers who are interested in 2D analysis tried to create a new method and, consequently, trolley setups had emerged. These setups are primarily made up of cameras placed on the trolleys, which are pulled by a person[9] or a vehicle[10] to record motion throughout the performance. For qualitative analyses, this method is quite practical and useful. On the other hand, for the quantitative analyses, one or more stationary reference points are needed so that the software can calculate the actual distances seen on the image. Since most of the software is built for stationary settings, it is particularly challenging to integrate the calibration process to the videos recorded by moving cameras. Therefore, researchers used additional measurement devices as tachograph[11,12] or speedometer[13-15], to calculate the horizontal velocity. Although using these devices provide vital information to researchers, a cord attached to athletes' body is needed, which can cause measurement errors[16] and discomfort[17]. It has been encountered only one peer-viewed study indicating horizontal velocity (H_v) can be estimated without using any extra apparatus. Lafontaine and Lamontagne (2003)[18] demonstrated approximately 3% deviation between the actual and experimental values using a sliding camera setup. The authors stated that the camera was moved by an assistant at the same speed as the object, which markers were placed on, and no estimation for the camera's velocity has been done.

Figure 1. Images of Lined-Up Cameras



When pros and cons are considered, it seems the video-based motion analysis is still the best option for technique analysis in swimming. As result of a detailed literature review, it has not been encountered a moving camera apparatus tested under scientific approaches or a study displaying results obtained by those apparatus for swimming. Therefore, the first aim of this study was to build a moving camera apparatus allowing kinematic measurements. The second aim of the study was to investigate the relation between results obtained by traditional stationary camera recordings and moving camera recordings regarding horizontal velocity.

MATERIALS AND METHODS

Kinematic Data Collection

Nine experienced male swimmers (height 178.3±6.3cm, weight 82.6±5.8 kg, age 22.3±3.86 years) participated in the study. The participants were asked to swim 25m for 3 times at relatively slow speeds in freestyle. Besides, the participants were instructed to swim in line with the bottom line (T-line) of the pool for 25m. To record performances, two camera setups were prepared. First, a stationary camera (Sony, PlayStation Eye, Japan) was connected to a notebook (Sony, VPCEB23FM, Japan) and placed perpendicular to the longitudinal edge of the pool. The distance between performance and the stationary camera was 10m. Second, two cameras were mounted on a custom-made trolley (Figure 2), which was pulled by a person. The first camera was placed on a modified tripod head at 0.8m height. The purpose of this camera was to record the above water images of the swimmer. The second camera was mounted facing down at the edge of the trolley. The purpose of this camera was to record images of floor markers that were lined up with 0.1m intervals. A high-performance notebook (ASUS, G53SX, Taiwan) is placed in a box mounted on the trolley to acquire data. The iPi Recorder (Ver. 3.2.6) software was used to record videos at 60fps to track the motion of a black marker which was placed on the lumbar region of the swimmers. Two separate calibration sticks were used for each camera recordings (stationary-15m and moving-2m). With the signal of the researcher, participants started to swim freestyle and recording was started. The trolley was pulled approximately at the same speed with the swimmer until his head reached 20m.

Figure 2. Moving Camera Apparatus

Kinematic Data Analyses

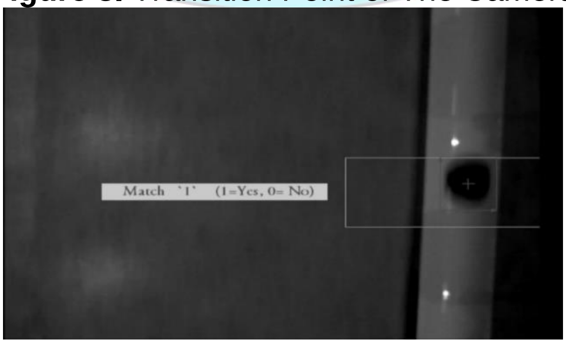
Nine out of 27 trials' recordings were included in the analyses. The rest were excluded because of occultation or dropped frames during recordings. Right hand's entry (the touch of the fingertips to the water surface) at the beginning of third arm stroke hand was determined as the beginning of the analyses. Therefore, images before this point were trimmed and recordings were synchronized by a new initial frame. Beyond this point, four sequential single arm strokes were included to the analyses. For the stationary camera, Tracker (Ver. 4.96) was used to calculate H_v of a swimmer. The marker was tracked by the auto-tracker feature of the software, and the calculations were handled by the software's own algorithm. To test the accuracy of the auto-tracker, two points, 5m apart from each other were digitized 100 times by the same feature.

Two calculations were performed to obtain H_v from moving cameras. To calculate trolley's velocity using floor markers an eight-step protocol was designed using National Instruments' Vision Builder for Automated Inspection (Ver. 2012) module. The aim of this protocol was to find the matches with the template images, which was the image of the black dot itself, and the corresponding frame number. When a match was found, that frame was accepted as a transition point of the camera (Figure 3). Frame numbers of matched images used to calculate the time interval that trolley covers 0.1m distances. The equation used for calculations was given below.

$$Vx_2 = Dis / [(Fn_{n+1} - Fn_n)*1/fps] \implies Vx_2 = 0.1/[(Fn_{n+1} - Fn_n)*1/60],$$

Dis = distance between floor markers
fps = recording speed of the camera
Vx_2 = Horizontal velocity of the trolley
Fn = Frame number

Figure 3. Transition Point of The Camera



Swimmers' H_v calculated independently from the trolley's H_v using the same protocol by following the marker on the swimmer. However, instead of the matching frames, this time differences in horizontal position of the marker were used to calculate the H_v of the swimmer as shown equation given below. The actual velocity of the swimmer was calculated by the addition of two velocities.

$$Vx_1 = (P_{n+1} - P_n)/(1/fps) ==> Vx_1 = (P_{n+1} - P_n)/(1/60)$$

$Vx_1 = H_v$ of the swimmer
P = Position of the marker
fps = recording speed of the camera

Statistical Analyses
Velocity data obtained from the moving camera apparatus and stationary camera were smoothed and interpolated by negative exponential interpolation with a sample size of .03 and 3rd-degree polynomial function using Sigmaplot (Ver. 12.5). The first two single-arm strokes were considered as the first cycle (C1) and the following two as the second cycle (C2). By this assignment, 18-time series couples were created. Since the H_v curve shapes very similar to sine association – non-linear – non-monotonic curves, as defined in the study of Santos et al. (2014)[19], Hoeffding's D measure was used to investigate the independence of data series. The alpha level was set at .05 for all tests. Statistical analyses were carried on using Wolfram Mathematica Software (Ver.11.0).

FINDINGS
The descriptive statistics showed that the error rate of the auto-tracking tool of the Tracker software was found below %0.1 (approx. ±4cm) for the 5m distance. This non-significant error rate indicated that the position of the camera and distortion of the lens did not affect the reliability of the measurement.

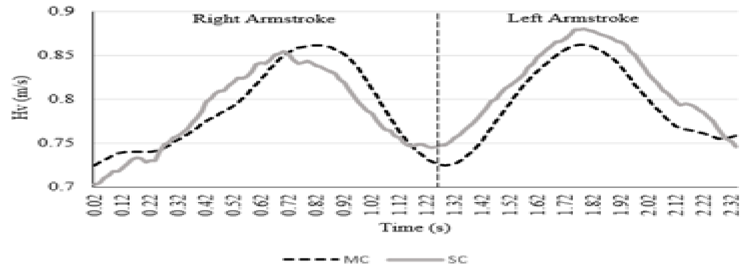
For all couples, Hoeffding's D measure tests identified significant ($p<.05$) dependencies between data series. Together with the statistical analyses results, descriptive information about trials shown in Table 1. In addition, Trial 1's data couple was given below as an example to display the relation between data series (Figure 2).

Table 1. Dependencies of the time series

			Swimmer's Horizontal Velocity (m/s)				Hoeffding's D Measure	
			M	SD	Min.	Max.	D	p
T_1	C_1	SC	.87	.09	.79	.99	.30	<.001*
		MC	.85	.06	.75	.96		
	C_2	SC	.84	.08	.76	.89	.46	<.001*
		MC	.86	.04	.80	.94		
T_2	C_1	SC	.82	.12	.68	.99	.25	.002*
		MC	.82	.06	.73	.94		
	C_2	SC	.82	.11	.68	.97	.49	<.001*
		MC	.84	.06	.75	.97		
T_3	C_1	SC	.80	.08	.70	.88	.53	<.001*
		MC	.80	.05	.72	.87		
	C_2	SC	.80	.08	.67	.88	.39	<.001*
		MC	.80	.05	.69	.88		
T_4	C_1	SC	.84	.10	.72	.96	.46	<.001*
		MC	.87	.05	.77	.95		
	C_2	SC	.81	.10	.70	.93	.49	<.001*
		MC	.89	.05	.80	.98		
T_5	C_1	SC	.80	.09	.70	.92	.46	<.001*
		MC	.78	.06	.67	.87		
	C_2	SC	.82	.08	.73	.90	.34	<.001*
		MC	.84	.05	.71	.90		
T_6	C_1	SC	.97	.03	.90	1.03	1.00	<.001*
		MC	.96	.03	.89	1.02		
	C_2	SC	1.05	.10	.95	1.11	1.00	<.001*
		MC	1.04	.05	.94	1.10		
T_7	C_1	SC	.78	.10	.66	.91	.29	.001*
		MC	.78	.05	.67	.88		
	C_2	SC	.83	.08	.75	.90	.23	.002*
		MC	.82	.04	.75	.90		
T_8	C_1	SC	.77	.10	.62	.90	.29	.001*
		MC	.78	.05	.69	.88		
	C_2	SC	.80	.09	.71	.88	.28	.002*
		MC	.80	.06	.71	.91		
T_9	C_1	SC	.79	.10	.64	.93	.22	.005*
		MC	.77	.05	.68	.88		
	C_2	SC	.81	.10	.65	.92	.28	.001*
		MC	.84	.04	.75	.91		

Note. T_x= Trial Number, C_x = Stroke Cycle, SC= Stationary Camera, MC= Moving Camera, *= Statistically Significant, (α =.05)

Figure 4. Horizontal Velocities of One Armstroke Cycle



Note. MC=Moving Camera, SC=Stationary Camera

DISCUSSION

The purposes of this study were to build a moving camera apparatus for kinematic analyses and investigate the accuracy. The use of moving camera apparatus provided some convenience and caused a reduction in workload during measurements. First, there was no need to place a calibration object in the pool. The calibration tape placed on deck was clearly visible without being affected by the water clarity or bubbles. Second, since the pixel size did not change throughout the recording, only one calibration frame was used at the beginning of the recording. Third, there was no need to attach an extra apparatus (belt or cable) to the swimmer's body.

In advance of the discussion on statistical test results, explaining why the smoothness of data series (as can be seen on Figure 4) was different would be explanatory. The swimmer's velocity calculated by the stationary camera recordings were done using positions of the marker in sequential frames. On the other hand, when moving camera apparatus was used, swimmers' velocities calculated by using 10cm transition points. Since the 3rd-degree polynomial interpolation method used to equalize sample size, the velocity curves became smoother.

The results of Hoeffding's D measure test indicated significant dependencies for data series calculated using the moving camera apparatus and the stationary camera recordings. As seen in the presented example, the increase and decrease in intra-cyclic horizontal velocity drew a very similar trajectory. When the couples were reviewed, it seems the differences increased at the peak points (negative or positive) relatively. However, the deviation never exceeded .05 m/s for all measurements. Also, the deviation (or error) in this study was considerably less in comparison to Lafontaine and Lamontagne's (2003)[18] study.

There are very few studies in which kinematic analysis is performed from images recorded using a moving camera. A study similar to our study in swimming has not been encountered in the literature. The results of two different studies, one measuring the amount of hoof slippage during the contact phase of horse stride[20] and the other examining human walking and running mechanics[21] are in line with the results of our study. The shared results of the studies show that the positions of the markers in 2- and 3-dimensional space can be tracked using moving cameras. Consequently, both the measurement capabilities of the moving camera apparatus and the results of the analysis indicated that this apparatus is suitable for studies on 2-dimensional velocity calculation.

Conflict of Interest

We have no conflicts of interest to disclose.

Ethical Approval

Ethical approval was given by the Ethics Committee of Nevşehir Hacı Bektaş Veli University with the number 2020.17.241 to conduct this study.

Acknowledgements

This study supported by the Nevsehir Haci Bektas Veli University Scientific Research Projects Department under the Grant no NEUBAP16S20.

REFERENCES

1. McGinnis PM. (2013). Biomechanics of sport and exercise. Human Kinetics. IL, 383-393.
2. Richards J. (2008). Biomechanics in clinic and research an interactive teaching and learning course. Elsevier. Edinburgh, 243-247.
3. Gonjo T., Olstad BH. (2021) Race analysis in competitive swimming: A narrative review. International Journal of Environmental Research and Public Health. 18(1), 69-75.
4. Craig AB., Pendergast DR. (1979). Relationships of stroke rate, distance per stroke, and velocity in competitive swimming. Medicine and Science in Sports. 11(3), 278-283.
5. Mooney R., Corley G., Godfrey A., Osborough C., Quinlan L., ÓLaighin G. (2015). Application of video-based methods for competitive swimming analysis: A systematic review. Sports and Exercise Medicine. 1(5), 133-150.
6. El-Sallam AA., Bennamoun M., Honda K., Lyttle A., Alderson, J. (2015). Towards a fully automatic markerless motion analysis system for the estimation of body joint kinematics with application to sport analysis. Paper presented at the GRAPP. Berlin. Almanya, 58-69.
7. Magalhaes FA., Sawacha Z., Di Michele R., Cortesi M., Gatta G., Fantozzi S. (2013). Effectiveness of an automatic tracking software in underwater motion analysis. Journal of Sports Science & Medicine. 12(4), 660-667.
8. Chiari L., Della Croce U., Leardini A., Cappozzo A. (2005). Human movement analysis using stereophotogrammetry: Part 2: Instrumental errors. Gait & Posture. 21(2), 197-211.
9. Strzała M., Krężałek P., Kaca M., Głąb G., Ostrowski A., Stanula A., Tyka A. (2012). Swimming speed of the breaststroke kick. Journal of Human Kinetics. 35(1), 133-139.
10. Mason B., Mackintosh C., Pease D. (2012). The development of an analysis system to assist in the correction of inefficiencies in starts and turns for elite competitive swimming. Paper presented at the ISBS-Conference Proceedings Archive. Melbourne. Australia, 249-252.
11. Michaela B., Jaroslav M., Jan Š., Hana L. (2016). Biomechanical analysis of front crawl arm stroke and leg kick by tachograph measuring system. Ovidius University Annals, Series Physical Education & Sport Science, Movement & Health. 16, 293-300.
12. Sidney M., Paillette S., Hespel J., Chollet D., Pelayo P. (2001). Effect of swim paddles on the intra-cyclic velocity variations and on the arm coordination of front crawl stroke. Paper presented at the ISBS-Conference Proceedings Archive. Sanfransico. USA, 39-42.
13. Feitosa WG., Costa MJ., Morais JE., Garrido ND., Silva AJ., Lima AB., Barbosa TM. (2013). A mechanical speedo-meter to assess swimmer's horizontal intra-cyclic velocity: validation for breaststroke and butterfly stroke. Paper presented at the ISBS-Conference Proceedings Archive. Taipei. Taiwan, 12-16.
14. Leblanc H., Seifert L., Tourny-Chollet C., Chollet D. (2007). Intra-cyclic distance per stroke phase, velocity fluctuations and acceleration time ratio of a breaststroker's hip: A comparison between elite and nonelite swimmers at different race paces. International Journal of Sports Medicine. 28(2), 140-147.
15. Puel F., Seifert L., Hellard P. (2014). Validation of an inertial measurement unit for the determination of the longitudinal speed of a swimmer. Paper presented at

the Proceedings of the XIIth International Symposium for Biomechanics and Medicine in Swimming. Canberra. Australia, 484-489.

16. Morouço P., Keskinen KL., Vilas-Boas JP., Fernandes RJ. (2011). Relationship between tethered forces and the four swimming techniques performance. Journal of Applied Biomechanics. 27(2), 161-169.
17. Dadashi F., Millet G., Aminian K. (2013). Inertial measurement unit and biomechanical analysis of swimming: An update. Schweizerische Zeitschrift für Sportmedizin und Sporttraumatologie. 61(3), 28-33.
18. Lafontaine D., Lamontagne M. (2003). 3-D kinematics using moving cameras. Part 1: Development and validation of the mobile data acquisition system. Journal of Applied Biomechanics. 19(4), 372-377.
19. Santos S., Takahashi DY., Nakata A., Fujita A. (2014). A comparative study of statistical methods used to identify dependencies between gene expression signals. Briefings in Bioinformatics. 15(6), 906-918.
20. Holden-Douilly L., Pourcelot P., Chateau H., Falala S., Crevier-Denoix N. (2013). A method to minimise error in 2D-DLT reconstruction of non-planar markers filmed with a moving camera. Computer Methods in Biomechanics and Biomedical Engineering. 16(9), 929-36.
21. Bernardina GR., Monnet T., Cerveri P., Silvatti AP. (2019). Moving system with action sport cameras: 3D kinematics of the walking and running in a large volume. PloS One. 14(11), e0224182.