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METHODOLOGY / KINESIOLOGY

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Improving the movements of basic karate techniques with the use of motion capture and mathematical modeling. The concept of a research project

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Abstract:
The purpose of this paper is to provide a method for mathematical modelling of martial arts and combat sports with the use of motion capture. The paper employs mathematical and computerised methods to analyse the movement dynamics in sports karate. Movement dynamics is one of the basic components of evaluating the sports level of a sports fighter (competitor). Modern computer technologies enable recording (capturing) and analysing physical values; they also enable statistical processing of this data. The research previously conducted at the University of Rzeszów studied an arbitrarily selected movement. The goal of the project is to evaluate the differences in the captured physical parameters which occur between novice fighters and recognised masters. This approach will enable instructors to define these differences, which should assist in selecting next training directions. Repeated capturing of the same movement will eliminate random factors. The purpose of statistical work is to eliminate measurement errors of the capturing instruments which trace the position of markers and of the instruments which record other physical quantities. One of the crucial elements of this research is the comparison of experimental results with applicable reference literature, where the latter proves that there is no mathematical model which describes the motion of the entire body of a fighter. The reference literature in the project description concerns the measurement of physical values of specific movement components, especially their maximum limit values.

Introduction

We are looking for the answers to several questions. What is the genuine contribution of the problem resolution to the given scientific discipline (existing knowledge in the field of the research)? Is the problem new or continued from the international perspective? To what extent does the problem verify existing approaches and legacy knowledge?

Research methodology in sport sciences must be tailored to the specifics of the tested object [Cynarski, Obodyński 2003; Obodyński, Cynarski 2003]. The area of martial arts and combat sports, teaching the techniques of fighting and all methodology of training causes multidisciplinary approach[1]. In this case, we are interested in the research area of movement - karate techniques.

The genuine contribution to the lore and tradition of martial arts consists in binding graphical movement recording techniques with mathematical modelling and simulation. This is intended to develop a new descriptive quality for the methods based on parallel analysis of multiple trajectories, velocity and acceleration of dozen-odd markers [*cf*. Jabłoński, Klempous, Majchrzak 2005; Wajs 2007; Fergus *et al.* 2008]. The digital movement image recording technology is well known, as are the analytical methods for this movement. However, only by combining both these approaches into one system intended to solve the problem of improving

[1] More about the specificity – see: Cynarski 1998, 2000; Jakhel 1998; Cynarski, Momola 2005; Cynarski, Obodyński 2005; Cynarski, Sieber 2006; Hall 2006; Cynarski, Kudłacz 2008; Kruszewski *et al*. 2008; Obodyński, Cynarski, Witkowski 2008.

movement in martial arts / combat sports is a novelty unique to all available reference literature in the world [*cf*. Zvonar *et al*. 2012].

The primary difference in the approach to the problem investigated in this research project and the difference from reference sources lies in describing the body movement with a vector of five functions [f(x,t),f(y,t),f(z,t),f(v,t),f(a,t)]. The number of individual vectors equals the number of body markers. 21 body markers translate into 105 functions which define the mathematical model of a fighter's movement. This descriptive model of fighter's movement gives new potential opportunities for further research. The opportunities are implied by the use of mathematical analysis apparatus in the investigation of function properties. In the algorithm processing, the original data requires filtering methods to eliminate artifacts and smooth out the digital data. Then the filtered digital data can be processed by an algorithm of approximation to obtain a temporally-continuous form; the original data are discrete in time. The integral criteria introduced to the movement quality testing shall enable a complex assessment of the movement by using the concept of time function intervals. The maximum values of individual physical quantities, which dominate the reference literature, are only a part of this problem's description.

The research in the project is focused on a comparative analysis of martial movements which involve simple hand punches (*tsuki-waza*) and kicks (*keri-waza*) performed by a master and a novice student, or a sports fighter. The analysis shall enable optimisation of performance and improvement of teaching the selected movement technique. This applies to karate, fencing and other martial arts in sports (boxing, kick boxing, *jujutsu*).

Several basic karate blows and moves have been selected for the research conducted so far by the project author team. Among the *tsuki-waza, gyaku-zuki* is one of the most basic moves, i.e. a punch executed by the back arm, or reverse punch. Its performance requires the coordination of the back leg, twisting the hips, contracting the abdominal muscles, a slight turn of the shoulders, finished by extension of the arm. In the left front stance (*zenkutsu-dachi*), the right arm deals the punch with the *seiken* surface. One of the simpler and basic kick techniques is the straight thrust kick to the front, i.e. *mae-geri kekomi*. It can be dealt from a free combat stance by the back leg. This requires good coordination and proper litheness of the body. The target should be hit by the foot part called *chusoku* in Japanese. The foot approaches the target and retracts on a trajectory approximated to a section of a straight line. In both techniques, the hand or the feet should hit an imaginary target of the central plane at the height of the solar plexus. The important parameters of movement are the terminal speed, the precision of hitting the target and the movement trajectory which should be approximated to a straight line (hence providing the shortest distance to the target). The comparative analysis will focus on the velocities of the techniques performed "in air" and during breaking of standard practice boards.

The scientific purpose of the project

The scientific purpose of this project is to develop a mathematical model of movements in sports martial arts, built with the use of mathematical analysis and mathematical statistics. The input data for the research is gathered with the use of digital cameras. The adopted data gathering systems are motion capture and WF-MOTION. There are three specific project performance goals:

— To build a mathematical model of a sports fighter. The fighter's movement can be described with selected physical quantities in the function of time. The basic movement model is defined by a vector of five functions: f(x,t), f(y,t), f(z,t), f(v,t), and f(a,t) for each marker placed on the fighter's body according to the research protocol. This gives 105 functions of movement in time for 21 body markers. The functions describe the movement in a system of x, y and z coordinates, as well as the velocity v and the acceleration a.

— To develop of a method which enables comparing a given movement of competitors who learn martial arts with the captured movement of a renowned master to define the quality criterion of the movement which is suitable in the training process.

— To perform functional tests of the developed movement improvement method for the training systems of selected martial arts.

The end result of the project is the mathematical model of the sports karate fighter movement, a database with the atlas of marker movements captured from ten-odd fighters, and the formulation of the fighter movement quality.

The end result will also include a unique computer test stations for digital capturing of movement and other physical values, e.g. velocity and acceleration. Lastly, the end result will produce algorithms for modelling and statistical analysis of movement with the use of mathematical methods which should help train new fighters and improve these training methods.

The importance of the project results from the integration of the research potential of three units at the University of Rzeszów: the Faculty of Physical Education, the Faculty of Medicine and the Institute of Computer Science, with cooperation with some foreign researchers. The integrated approach is implied by the project's goals.

The original source of knowledge required to accomplish the project is the scientific staff of the Faculty of Physical Education. The research back-up of the Faculty is a team of fighters who represent master-level knowledge of martial arts, including several world champions.

The Faculty of Medicine operates a SMART-D digital image recording system and a team of specialist operators of this equipment; it will be used to obtain the required input data. A team of IT specialists shall be responsible for modelling of physical phenomena with tools of mathematical analysis and statistics; they will also build the required IT environment for the project. The IT team has developed a system called WF-MOTION, which may be used in the project to research body movement, albeit to a limited extent. The primary movement capturing system of the project is SMART-D.

The Faculty of Physical Education at the University of Rzeszów provides teaching classes for combat sport instructors, which is a part of the University's chartered operations. The advancement of motion capture and computer technologies provides opportunities for developing new training methods and improving the existing ones. The development and mastering of new techniques for measurement of physical quantities provide unique opportunities for verifying the training methods already in use. Precisely measured physical quantities which describe fighter's movements may improve the quality of training. This will be especially useful at the follow-up checks of the training process.

The importance of the project is derived from the established goals of its performance. The essence of the project is the proposal of developing a mathematical method of analysing the motion dynamics of martial sportsmen by recording the position of 21 body markers; the method will mainly involve mathematical analysis and statistics for spatial identification of movement trajectory.

The purpose of the project is to identify relationships between physical quantities which are critical to movement dynamics. This applies the expected progress in training of fighters by meeting the goals established by their instructors. A thorough analysis of movement components, based on the data collected in the database in the form of recorded digital camera images, should provide the input for scientific papers and doctoral conferment. The project can be accomplished by the cooperation of several dozens of individuals who operate specialist equipment. A financial grant for the project will be a significant support for the assumed performance of research concepts[2].

Research methodology

In order to accomplish the research to date at the University of Rzeszów, an interdisciplinary task team was formed. The team includes martial arts specialists from the Faculty of Physical Education, a group of operating personnel for the BTS SMART-D system from the Faculty of Medicine, and a group of IT specialists which specialize in mathematical modeling of physical processes and computer programming.

The research facility of the applicant is the BTS SMART-D system operated at the University of Rzeszów. The system is intended to operate as a reference system for the custom-built WF-Motion system, which has been created for this project. SMART-D can serve as a reference due to its advanced processing and software solutions. SMART-D contains the Advanced Blob Analysis algorithm. SMART-D enables reconstruction of missing data by correlation of information captured by different cameras. Multi-dimensional calibration allows creating groups of cameras to collect data from different sections of space. SMART-D detects and records the three-dimensional positions of passive markers (blobs) with the diameter of 1 mm to 20 mm, located on the surface of a moving object. The image from each camera is processed in real time by the Advanced Blob Analysis algorithm to identify and calculate the position of the marker.

Currently there are several motion capture techniques. Nearly all of them are based on two sources of data capture. The first one is a digital or analogue camera, and the second one is a motion sensor. Both recording methods should deliver an identical result. The result of their operation is the recording of the spatial position of the marker. There are visual systems which do not use markers or blobs due to their principle of operation. In this case, the video sequence recording involves recognition of selected points of the human skeleton. Processing of results is the translation of a simple kinematics problem into a reverse kinematics problem. In practical terms, this approach converts the information on the spatial location of skeletal points into angles and lengths of selected members. The

[2] Our team is preparing a proposal for funding for the project.

members are the appropriate bones of the human skeleton; their lengths remain constant during the recording time. The achievements in motion capture so far enable comparison of movement sequences. An open question remains how to automatically assemble complex motion sequences from camera recordings [*cf*. Akyildiz, Kasimoglu 2004; Kaimakis, Lasenby 2004; Sundaresan, Chellappa 2005; Corazza *et al*. 2006; King, Paulson 2007; Rosenhahn, Brox, Seidel 2007; Gianino 2010].

The precision of recording/capture systems significantly depends on the parameters of the cameras used to record images. Among these parameters, a noteworthy one is the frequency of recording successive still images. This parameter is expressed as fps (*frames per second*). Another significant parameter is the camera resolution, which is expressed in pixels and usually confined to the range of 256x256 to 1024x1024 pixels. This is followed by the light wavelength range used in recording the images, i.e. visible light or infra-red. Motion detection method is yet another parameter. There basically are two methods: marker and non-marker.

Marker methods employ suitably laid-out markers. The markers usually are small spheres, or blobs. The purpose of these markers is to identify the parts of the human skeleton during performance of suitable motion sequences. In this method, the images are usually recorded in infra-red light. The basic portion of the marker surface is a reflective substance. Passive markers are lighted by IR-light emitting diodes. The diodes are integrated with the camera. The IR light is reflected by the markers back to the camera. The discussed systems also employ active markers, just as it is the case of WF-Motion, a system developed by the Faculty of Physical Education at the University of Rzeszów. Active markers are light sources.

The image recorded by the camera is composed of light marker points on a dark background. By using various methods of programming and image segmentation, it is possible to calculate the positions of the markers in the image; here the precision depends on the resolution and the fps rating of the cameras. The positions of the markers calculated in a 2D image enable algorithm assembly of movement in 3D space. The applied system includes several to ten-odd digital cameras which record images in IR light. The adopted system enables laying out the markers in accordance with the following international protocols: DAVIS, HELEN HAYES, RAB, LAMB, OXFORD FOOT MODEL, and FULL BODY. Each protocol establishes the number of markers and their layout on the human body.

The planned test shall be performed on a group of *karate shotokan* fighters (ITKF version), "the black belts", *idokan karate* athletes, and on a comparative group of students from the UR Faculty of Physical Education. The analysis of movement of the aforementioned techniques may become useful in teaching *karate shotokan* and other or identical styles adopted in Olympic *taekwondo* of the WTF, modern sports and self-defence *jujutsu* and kick boxing, as well as in the so-called sports training control.

The research shall be then extended onto sets of application in the teaching of *jujutsu* and *judo*. Here the purpose is to perform a comparative analysis of martial art movements, e.g. entry positions of throws performed by an expert and a novice or sports fighter, or in *kendo*. This also applies to traditional fencing strokes, also performed by an expert and a novice or a professional fencer. This will optimize the investigated movement to shorten the time required to teach the technique. The next step will involve an analysis of complex motion in technical forms (*kata*) [Cynarski, Obodyński, Litwiniuk 2008] and karate sparring.

The front thrust kick (*mae-geri kekomi*) as an example of the analysis of motion of a tracker on the foot by the trajectory of a system of coordinates x, y, z. Pattern of motion description for the analysis of captured movement trajectories.

Quickly fold the kicking leg and raise the knee to the chest. At the same time, extend its toes as high as possible and hold them in this position. The knee muscles of the kicking leg shall be relaxed, while the ankle and the knee of the resting feet shall be slightly bent and tensioned with the toes towards the target. The knee and the toes of the kicking leg shall be in the same vertical plane and pointed towards the target. The feet shall be lined with the axis of the shank. By employing a rapid movement of the knee and turning the hips by approx. 45˚, kick straight ahead of the body to hit the target with the ball of the foot (*chusoku*). Then retract the kicking leg into the previous position while holding the knee close to the chest and lower it into the starting position. All of the aforementioned movements should form a single fluent motion without any pauses, so that the first movement of raising the knee adds impact to the violent kick. If the kick is towards the *chudan* zone, i.e. at the height of the solar plexus, the striking surface (*chusoku*) shall move towards the target along a straight line in the final section of motion. The front thrust kick is best performed from a stable stance. It can be done with the front leg or the back leg, or e.g. when stepping forward.

Description of the test stand and layout of markers

The projects assumes recording of the data from the markers laid out on the entire body of the fighter. The following illustrations (1-3) provide a proposed layout of the markers.

21 markers have been used so far. The illustration shows the layout of the markers on the fighter's body. The recording instruments record digital data as 63 functions of time (3 coordinates multiplied by 21 markers), since there are 21 markers and three axes of the system of coordinates (x, y, z). The time-space location of the markers is recorded at 120 [Hz]. Once the data collected by SMART-D is transmitted to the database, a computer system computes the motion trajectory in the system of coordinates x, y and z, and it also calculates the velocity and acceleration of each marker. The algorithms for calculating the trajectory in the x,y,z system, the velocity and the acceleration have been defined in Matlab-Simulink.

The mathematical model of movement kinematics and dynamics

The mathematical model of movement kinematics and dynamics allows demonstrating and understanding the difference between the theoretical model of motion and the actually recorded motion trajectory. Investigation of physical quantities of a given karate technique makes it possible to introduce elements of optimization in the process of mastering the move. Introduction of precise measurements of physical quantities allows determining the differences in training progress with selected and described motion trajectories in 2D and 3D space. The additional element is to develop the technique of digital recording of those physical quantities which are critical to motion dynamics. Developing the appropriate test stand which enables precise measurement of physical quantities is of utter significance. Example: concerning the *mae-geri* motion, one work [Gianino 2010] reports that the acceleration is 108 [m/s2] for the rotation of the hip, while its velocity is 19 [m/s]. These values seem excessive. The author does not specify the measurement method for these two quantities. The same work states that the tests were conducted with a digital camera with the frame rate of 25 [fps]. This gives an image each 0.04 [s]. The test was conducted on a (x,y) plane.

Professor Yoshio Kato (Takushoku University, Tokyo) reports the results of an experiment which involved EMG's and filming with a 64 [fps] camera. The recorded subject was the process of striking by fist. The results published by Kato are listed in the table 1.

The test was conducted on the punch made by a 2nd dan holder. The highest acceleration was recorded following the start of the motion. The listed value is 74 [m/s2]. Of course, the examples from older works such Nakayama [1966] are used only to fulfill the picture, as methodology and technological devices used then and today may cause different results.

The described project proposes the quantities which can be considered as movement quality criteria. The quantities are considered in reference to a chosen marker. The calculated quantities for marker 0 are listed below. Marker 0 was placed on the left hip joint of the fighter. The maximum acceleration value a_max is 6.5521e+004 [mm/s^2]. The maximum velocity value v_max is 1.7218e+003 [mm/s]. The average acceleration mean(a) is 6.0812e+003 [mm/s^2], whereas the average speed mean(v) is 467.8989 [mm/s].

Results of preliminary research

The table 2 lists the first 20 frames from the 553 frames recorded by SMART-D during the marker

Table 1. Fist velocity during a straight punch

Karateka	Velocity Average [m/s]	Velocity maximum [m/s]	Velocity terminal [m/s]
4th dan	5.06	7.1	5.16
2nd dan	3.25	6.71	4.48
8th kyu	2.88	4.68	2.9

Velocity of fists during an *oi-zuki*

Karateka	Velocity Average [m/s]	Velocity maximum [m/s]	Velocity terminal [m/s]
4th dan	5.84	12.64	8.21
2nd dan	5.52	11.45	7.78
8th kyu	3.35	7.1	4.56

[Source: Nakayama 1966, 1999: 294-295].

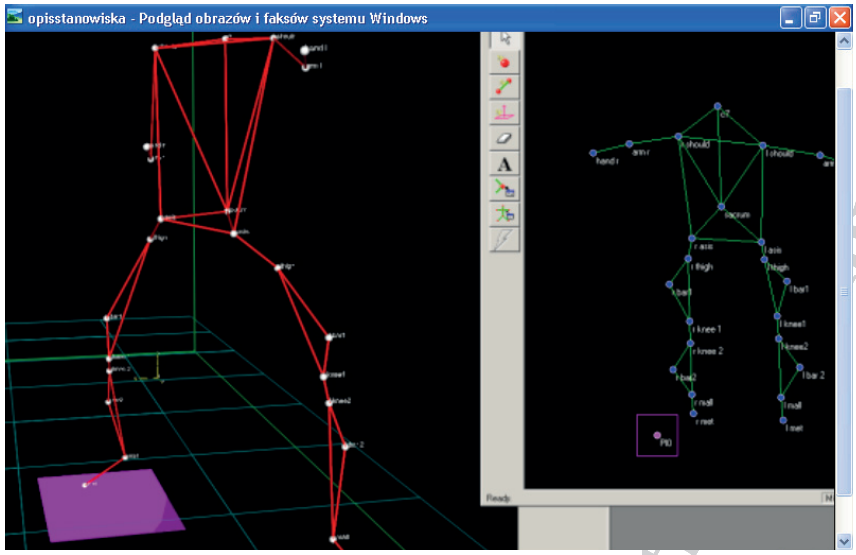

Fig. 1. The markers laid out on the entire body.

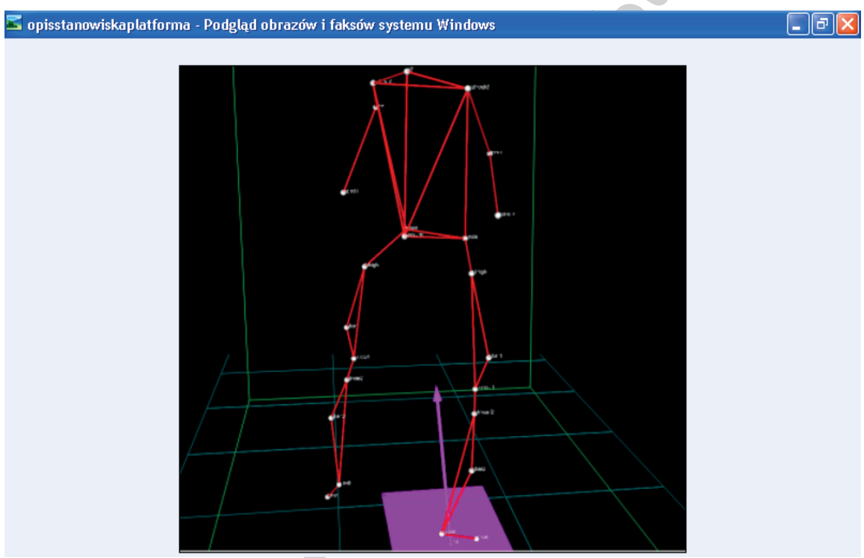

Fig. 2. The illustration presents the measurement of the pressure exerted by the left foot with the use of the SMART-D measurement platform. The measurement platform enables recording the foot pressure on the floor when the fighter is in motion, and it may serve as an additional element of the mathematical description of movement.

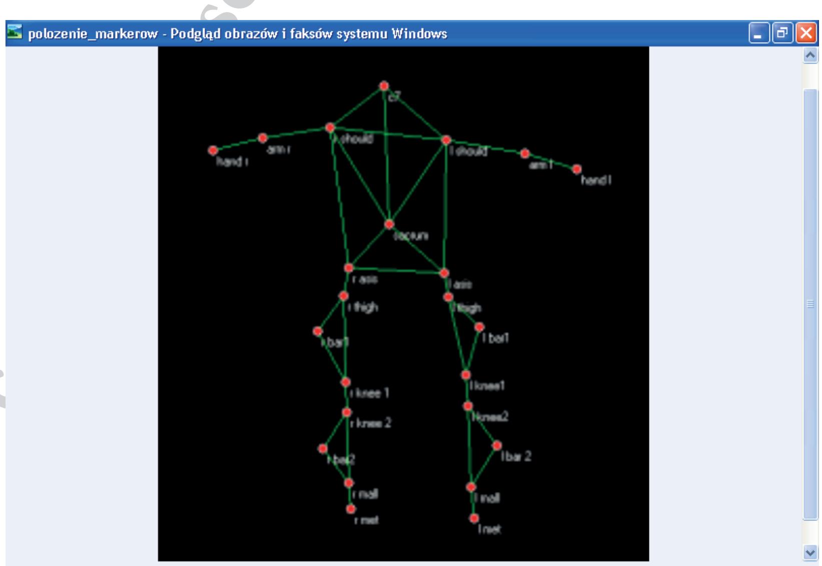

Fig. 3. Location of markers on karateka's body

Table 2. The first 20 frames

Type:	Point3Dtracks			
Measure unit:	mm			
Tracks:	21			
Frequency:	120Hz			
Frames:	553			
Start time:	0.00			
FRAME	**TIME**	**Marker 0**		
		X	**Y**	**Z**
1	0.000	283.248	886.749	158.187
2	0.008	283.358	886.797	158.428
3	0.017	283.570	886.821	158.676
4	0.025	283.791	886.806	158.881
5	0.033	284.016	886.845	159.087
6	0.042	284.434	886.865	159.307
7	0.050	284.654	886.841	159.390
8	0.058	284.871	886.830	159.611
9	0.067	285.225	886.845	159.887
10	0.075	285.488	886.870	160.070
11	0.083	285.794	886.877	160.231
12	0.092	286.010	886.968	160.331
13	0.100	286.273	886.996	160.515
14	0.108	286.614	886.924	160.712
15	0.117	286.770	886.941	160.851
16	0.125	287.122	886.910	160.965
17	0.133	287.647	887.026	161.193
18	0.142	288.289	887.119	161.489
19	0.150	288.810	887.239	161.882
20	0.158	289.194	887.377	162.287

0 capture. The entire test of this single movement is worth 63 columns (3 coordinates multiplied by 21 markers) and 553 lines of data. Each line includes the timestamp at the interval of 1/120 [s], since the recording frequency is 120 [Hz]. The data collected in this manner from the digital cameras are the input for the function: f(x,t),f(y,t),f(z,t) and for modelling the function f(v,t),f(a,t).

Trajectories of movement for marker 0

The calculated motion trajectories of each marker can be an important feature of movement improvements. The available graphical processing technology allows presenting the same trajectory in 2D and 3D systems. The system of axes in 3D space can be freely adapted, which facilitates the analysis. Improving the movement by basing on the trajectory analysis is possible if there are recorded reference movement trajectories of champions of a given sports discipline.

The trajectory plot of marker 0 in the Cartesian system of x,y,z is presented in the figure 4. The space of motion can be confined to a cuboid. The variation range for axis y is 600 mm to 1200 mm. The variation range for axis x is 200 mm to 1200 mm. The variation range for axis z is -50 mm to 250 mm. The plot of trajectory presented in this figure is an assembly of three functions, f(x,t), f(y,t), f(z,t) into one function, f(x,y,z,t).

The figure 5 presents the same trajectory of movement in a different system of coordinates. The system (x,y) is replaced by a system (x,z,y), which allows observation from a different perspective of the spectator.

The trajectory plot of marker 0 in the Cartesian system of x,z,y. The variation range for axis x is 700 mm to 1200 mm. The variation range for axis y is 200 mm to 1200 mm. The variation range for axis z is - 100 mm to 300 mm.

The same trajectory can be observed in a system of coordinates (y,z,x). Remember that the basic system of coordinates (x,y,z) referenced to the spectator has axis x in line with the fighter's direction of movement towards the hypothetical opponent. The perpendicular axis y points vertically up, towards the fighter's head, whereas

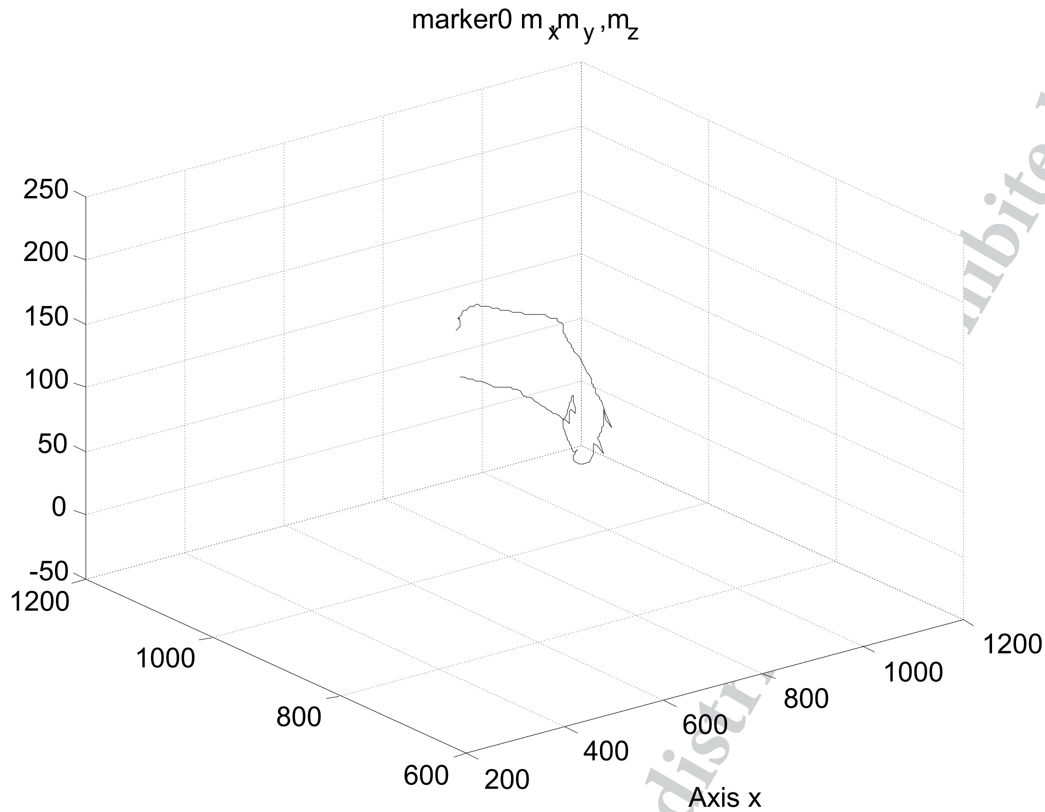

Fig. 4. The trajectory plot of marker 0 in the Cartesian system of x,y,z

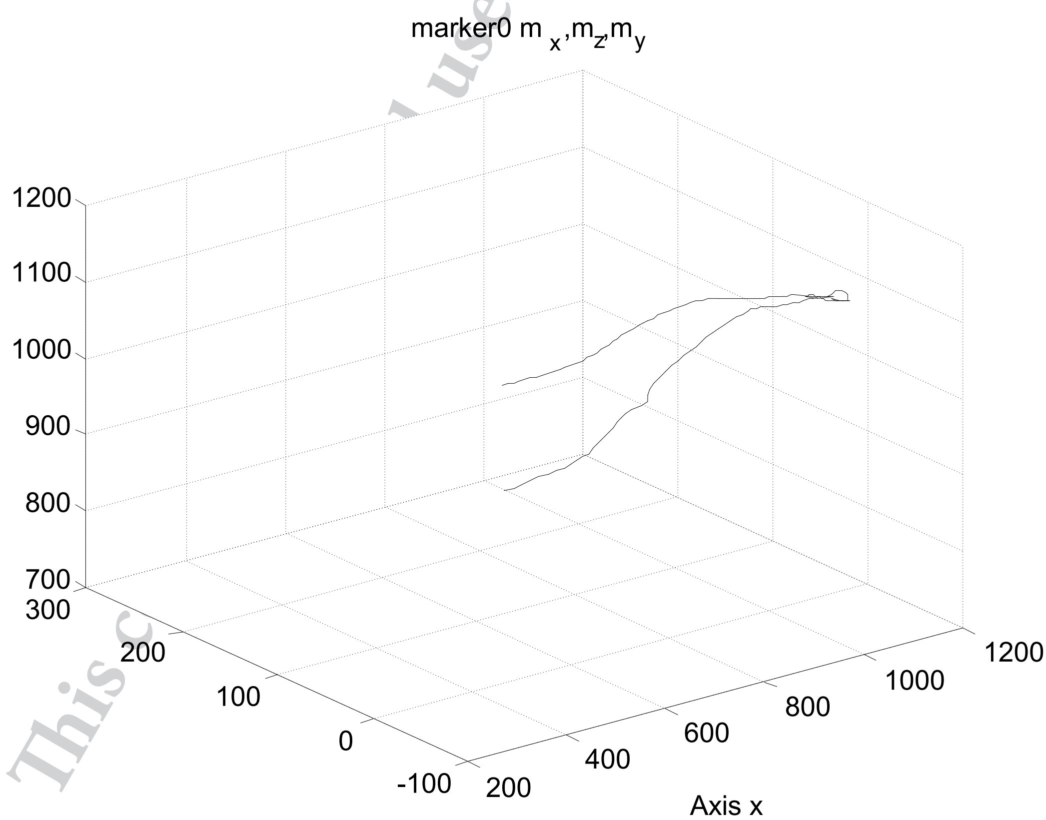

Fig. 5. The trajectory plot of marker 0 in the other system

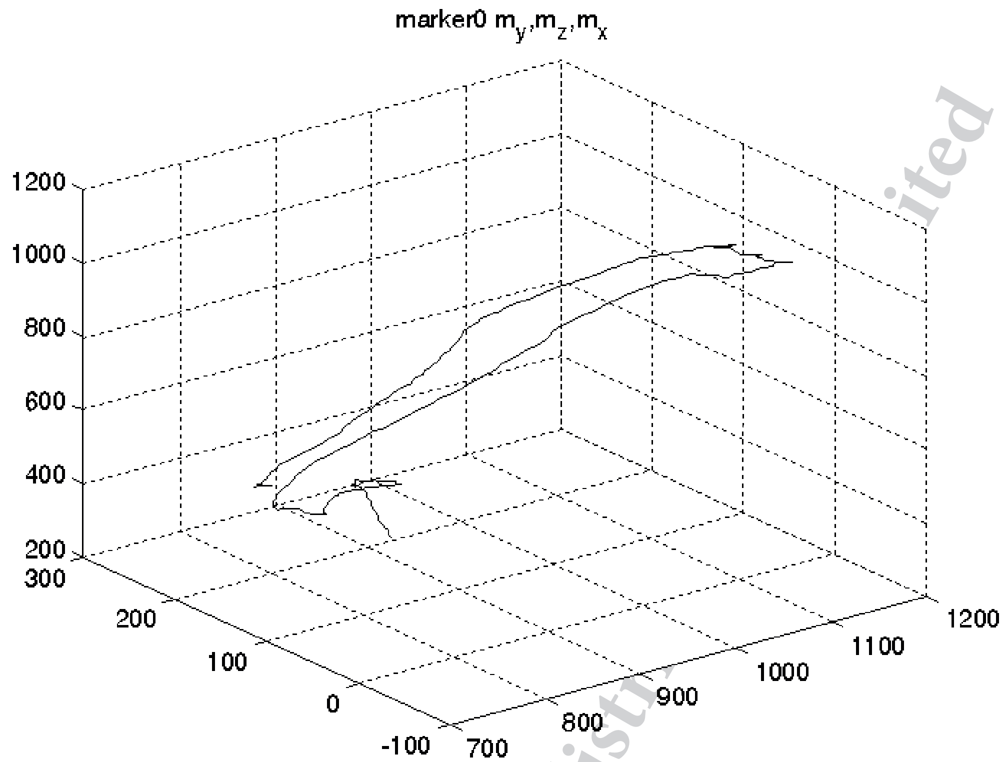

Fig. 6. The trajectory plot of marker 0 in the Cartesian system of y,z,x.

axis z is directed to the left, in perpendicular to the progressive motion of the fighter.

The variation range for axis y is 700 mm to 1200 mm. The variation range for axis x is 200 mm to 1200 mm. The variation range for axis z is -100 mm to 300 mm.

The space of motion for marker 0 is confined in a cube the limits of which can be calculated for the movement trajectory of the chosen marker. In plane x, the values max(m_x)-min(m_x) determine the range at 821.3920 [mm] at the values min(m_x)= 283.2480 [mm] and max(m_x)=1.1046e+003 [mm]. The values in plane y and z are calculated from the following formulas: max(m_y)-min(m_y) = 341.1140 [mm] and ax(m_z)-min(m_z) = 256.7240 [mm].

Velocity and acceleration of markers

The following are the charts of velocity and acceleration for the original data from digital cameras after complementing for the missing input data. The missing input data are caused by gaps in recording of the marker locations in space by some of the cameras. This is usually the effect of obscuring the marker, which makes it undetectable by the cameras. Due to artefacts, the values of velocity and acceleration in the charts are excessive.

The artefacts are especially evident at the location plots: the lowest function and the function in the centre of the figure.

Movement trajectories of marker r_should(er)

The trajectories of the marker on the fighter's shoulder and labeled r_should(er) are presented below in the system of coordinates x, y, z.

In order to analyse the motion precisely, the complete motion sequence is divided into one-second sections. 120 still images are recorded during 1 s. The following illustrations present the plots of the function which describes the location, with the functions of speed to the right.

The research accomplished so far imply problems which require solutions. The most important ones are complementation of missing data in the digital camera recordings. The algorithm for calculation the distance between trajectories in various systems of coordinates must be developed. Another important problem is to develop a method to compare the motions of a martial master to the motions of a novice in the form of a movement quality criterion. A difficult issue left to be resolved is the algorithm for filtering the input data recorded by the digital cameras, including elimination of artefacts.

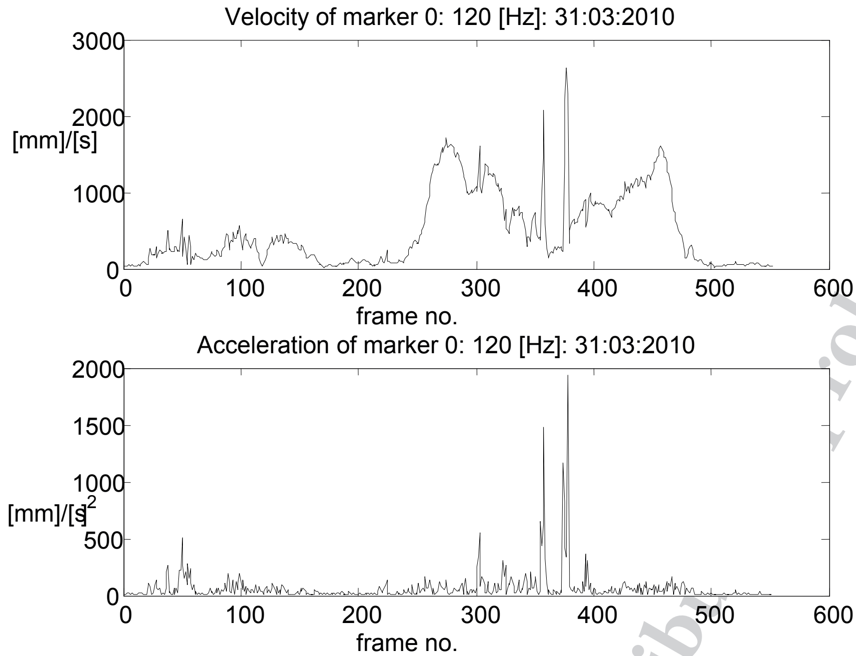

Fig. 7. The input data are presented in the charts as function f(v,t) in the top chart and f(a,t) in the bottom chart. The artefacts are visible between sample 350 and sample 400.

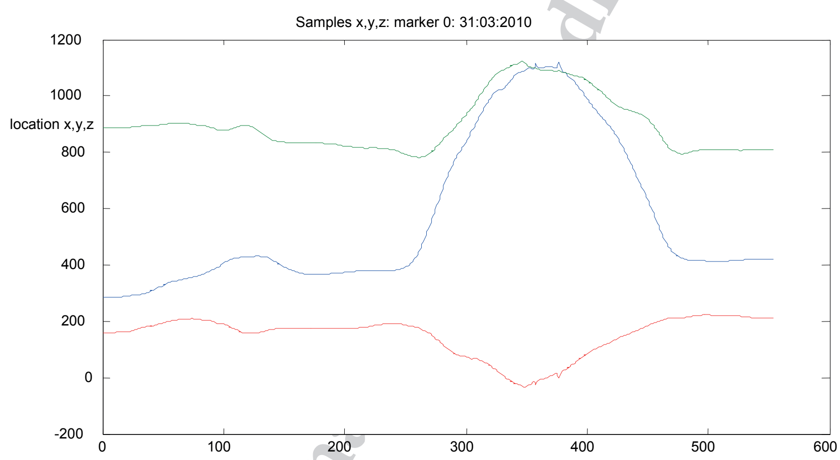

Fig. 8. The marker 0 location plots are defined by functions f(x,t), f(y,t) and f(z,t). The axis of time is represented by successive data samples, from 0 to 553, with the intervals of 1/120 [s].

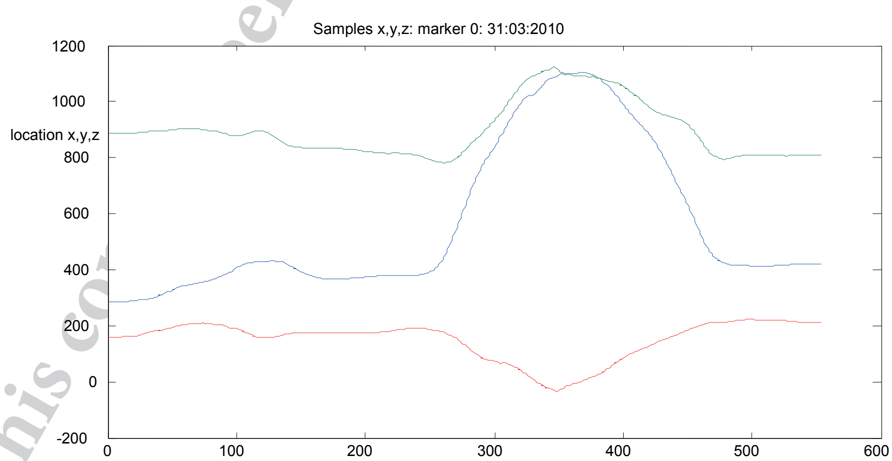

Fig. 9. The location plots without artefacts of marker 0. The artefacts occurred due to tension of the muscle to which the marker was attached. The graphs of velocity and acceleration are shown in the figure. The graphs below (10-11) represent functions f(v,t) and f(a,t).

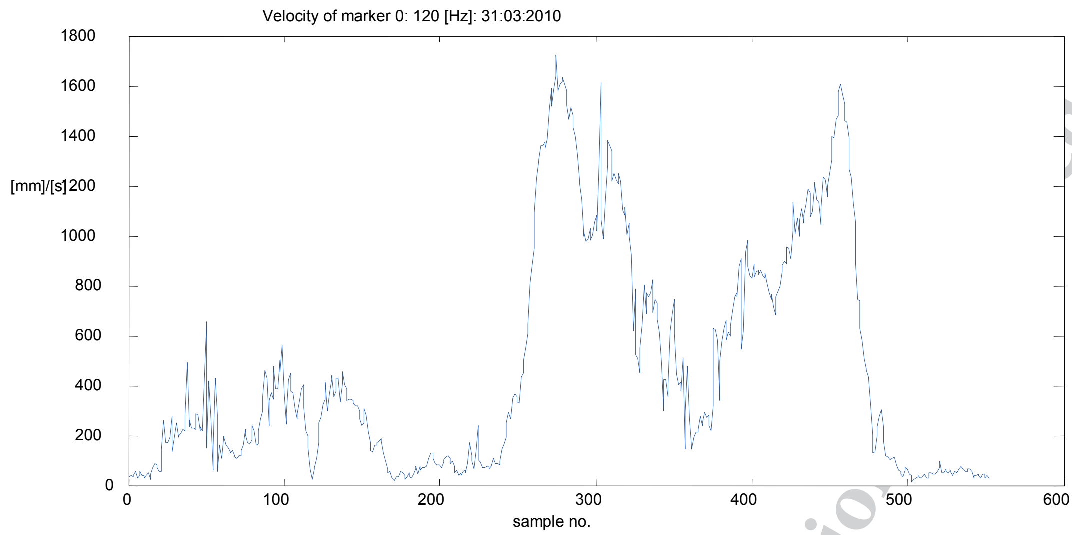

Fig. 10. Function f(v,t)

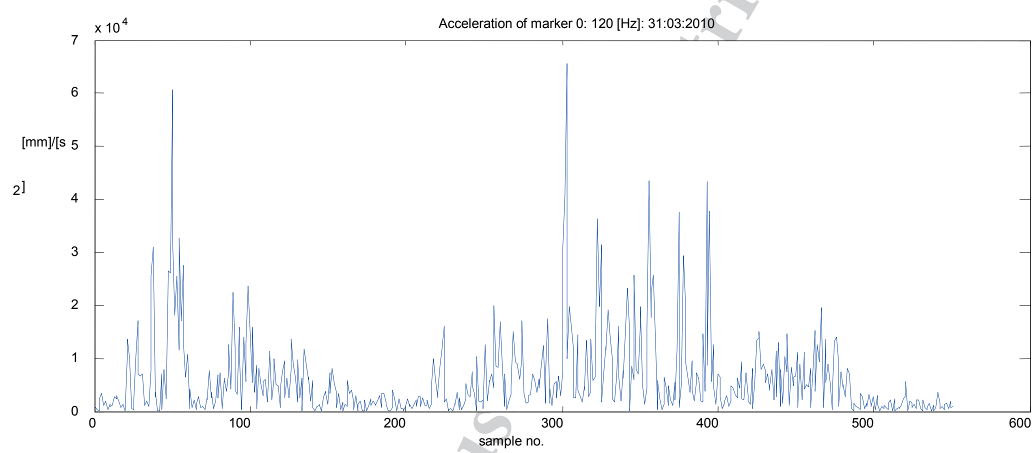

Fig. 11. The distance covered by marker 0 during 1/120 [s] is marked dx and as shown below. The distance is expressed in [mm] per 1/120 [s]. The total trajectory length d is 2.1523e+003[mm], i.e. the sum of all dx at the recording time for marker 0.

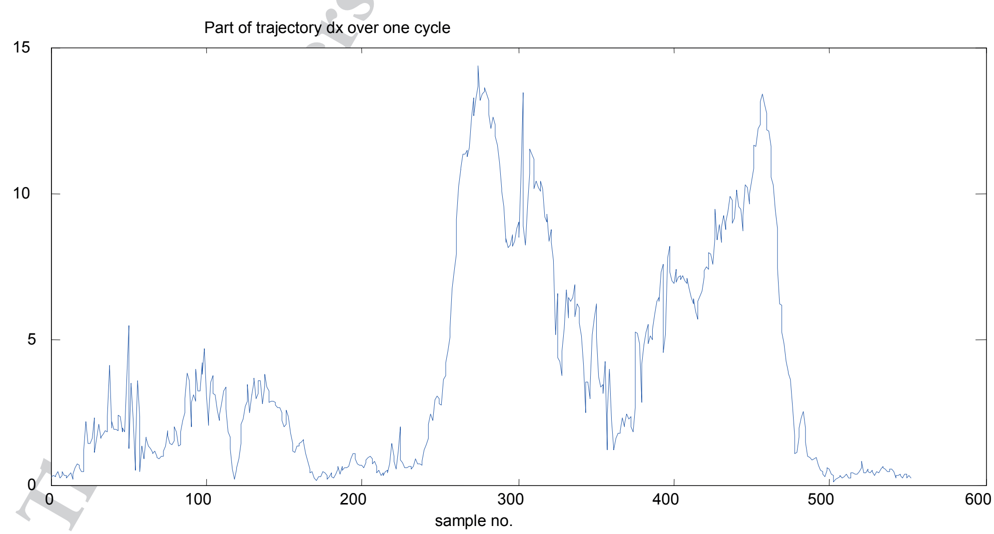

Fig. 12. The highest values of the distance covered in the time of 1/120 [s] is approx 15 [mm] at moment t≈300*1/120[s].

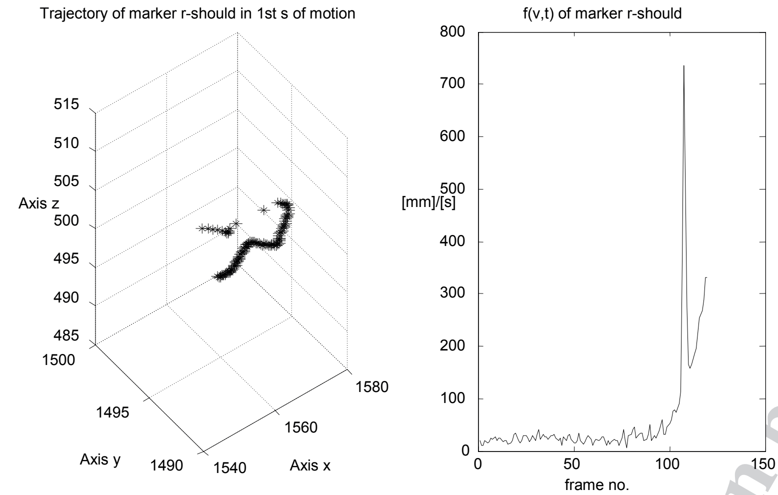

Fig. 13. Trajectory of marker r-should in 1st s of motion

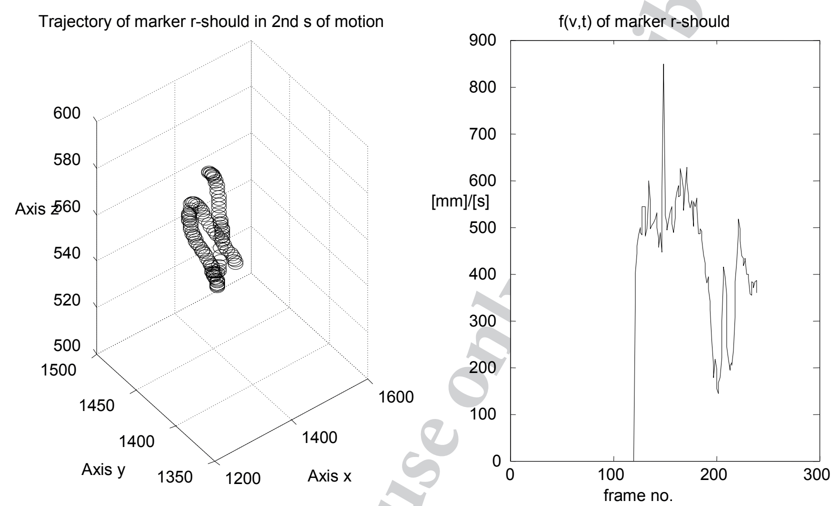

Fig. 14. Trajectory of marker r-should in 2nd s of motion

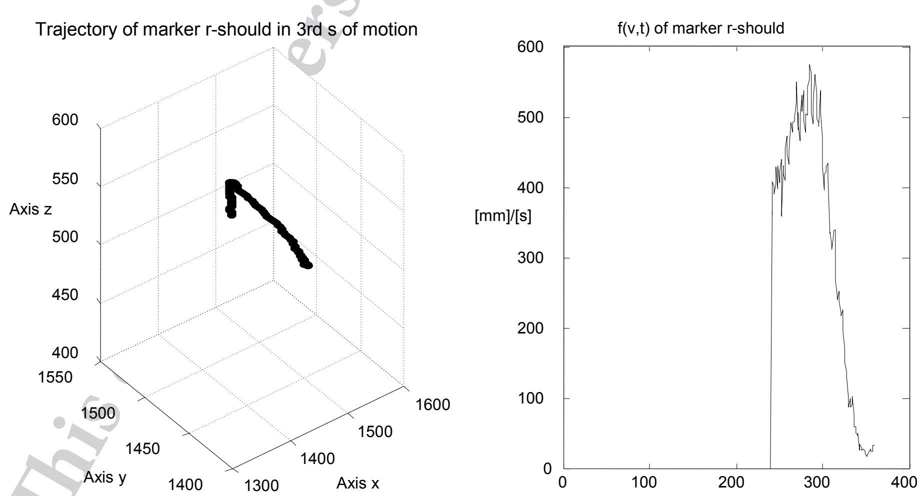

Fig. 15. Trajectory of marker r-should in 3rd s of motion

Discussion. Measurement of movement dynamics

The idea of applying computer-assisted movement analysis in teaching of karate and similar martial arts is applied by few researchers in some countries. However, foreign scientific institutions use motion capture in sports research. There are few works which use motion capture to investigate martial arts. For example, Sang Yeon Woo [2009] of South Korea investigated the basic kendo stroke (i.e. men) by employing four high-performance cameras (500 fps), while e.g. Kalichová *et al.* [2012] made a kinematic characterization of the Capoeira Bencao Kick.

António VencesBrito [2009] of Portugal analysed the kinetic motion pattern of a karate strike called *gyaku-zuki* dealt comparatively to a *makiwara* and into air. They were tested by VencesBrito *et al.* [2011], kinematic and electromyographic aspects of the karate punch (*tsuki*), and the front kick (*mae-geri*), too [VencesBrito *et al.* 2013]. Some other authors focus on the importance of stability and coordination motor abilities in karate techniques [Cynarski, Obodyński, Litwiniuk 2005; Kruszewski *et al.* 2008; Gianino 2010; Maroteaux 2012].

The dynamics of movement is a critical problem of martial arts. The reference literature provides applicable physical quantities collected by various research institutions around the world. The records mostly relate to velocity and pressure (i.e. force per unit of surface). In his "Dynamic Karate" (1966), Masatoshi Nakayama notes the work of the pelvic girdle and the shoulder girdle during *gyaku-zuki* [Nakayama 1999: 96-97]. Nakayama states that the pressure during the board breaking test (*tameshiwari*) with a *tsuki* is between 170 and 700 kG/cm2 [Nakayama 1999: 294-295].

In his description of *gyaku-zuki*, Miłkowski [1983] says that the velocity of the fist should be approximately 14 m/s. Fichner and Ruciński [1985] list the corresponding maximum velocities in metres per second: *oi-zuki* 5.7-9.8 m/s, *tettsui-uchi (oroshi)* 10-14 m/s, *shuto-uchi (tate)* 10-14/m/s, *mawashi-geri* 9.5-11 m/s, *mae-geri* 14.4 m/s, *yoko-geri* 9.9-14.4 m/s. Fechner published the data on the foot velocity in the kicks by renowned professional masters of the mat and of the ring. The *karateka* Bill Wallace would kick with his left foot at 26.8 m/s. Frank Dux, a *ninjutsu* master, achieved the world record in kick speed, i.e. 32.2 m/s.

Ernst [1992] lists the maximum velocity of the hand striking down at 14 m/s, at 9 m/s when striking forward, and as much as 60 km/h during kicking. The dynamics of karate techniques comes from the work of the entire body, i.e. the legs, the hips, the shoulders and the hands, which must be accounted for in the research [*cf*. Emmermacher, Witte, Hofmann 2010; Wąsik, Ferreira da Silva Santos, Franchini 2013].

Conclusions

The measurable effect of the problem researched in the project will be to develop a complex mathematical model which reflects the motion of a sports *karateka*.

The measurable outcome of the project performance is a new, unique test stand (complete with software and ready to record data), which will enable improvement of training method and expansion of the teaching at the University of Rzeszów. The said test stand will allow expanding new research topics consisting in improvement of movements in martial arts by digital recording systems and application of mathematical methods for modelling the movements in martial arts.

The measurable result is the new methods of research, including the methods of statistical modelling of sports fighters' and athletes' movement dynamics. Yet another result will be the registration and conferment procedure for a doctoral degree. The information collected in the project's database shall provide substance for scientific publications and presenting the research project results at scientific conferences in Poland and abroad.

The collection of the aforementioned motion parameters (vector quantities) and information on their changes will enable evaluation of karate mastery. In the sports karate, just as similar sports martial arts (boxing, kick boxing, *taekwondo* or fencing), proper precision and motion dynamics are critical to combat effectiveness. The results of this research should aid the process of sports training in order to optimise the performance of techniques, i.e. its precision (according to the master pattern) and dynamic parameters.

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Poprawa ruchów podstawowych technik karate z pomocą rejestrowania ruchu i modelowania matematycznego. Koncepcja projektu badawczego

Słowa kluczowe: nauka o sztukach walki, kinetyka sportowa, biomechanika, komputerowa analiza ruchu, karate

Streszczenie

W pracy wykorzystano techniki komputerowe do analizy dynamiki ruchu w karate. Dynamika ruchu zawodnika jest jednym podstawowych czynników oceny poziomu sportowego sportowca uprawiającego sporty walki. Współczesne techniki komputerowe pozwalają na rejestrację i analizę, a także na opracowanie statystyczne zarejestrowanych wielkości fizycznych. W pracy poddano analizie jeden arbitralnie wybrany ruch. Celem pracy jest ocena różnic jakie występują wśród zarejestrowanych parametrów fizycznych pomiędzy początkującym zawodnikiem a uznanym mistrzem. Podejście takie pozwoli trenerowi na zdefiniowanie tych różnic i powinno pomóc w określenie kierunku szkolenia. Liczne rejestracje tego samego ruchu pozwoli na wyeliminowanie czynników losowych. Celem opracowań statystycznych jest wyeliminowanie błędów pomiarowych aparatury rejestrującej położenie markerów i inne wielości fizyczne. Jednym z ważnych elementów przeprowadzonych badań jest konfrontacja uzyskanych wyników z odpowiednimi doniesieniami literaturowymi.