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The design of a striking dummy and the theoretical foundations of martial arts strikes

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Purpose: The aim of the research was to develop the design of a striking dummy and the theoretical foundations of martial arts strikes and to test its effectiveness in a pedagogical experiment. This paper presents the design of a striking dummy and the foundational theories behind martial arts strikes. We used modern microelectronics, including a diverse range of sensors, for executing a multitude of electromechanical measurements. Furthermore, we developed a software package for collecting, analysing and storing data from sports training. *Methods*: The TaePunchBag program, part of this setup, integrates several combat sports including boxing, taekwondo, kickboxing, karate and hand-to-hand combat. It classifies and evaluates various types of hand and foot strikes, conducting specialized tests to measure attributes such as speed, response to signals, force up to 800 kg and impact accuracy. *Results*: The article details the tasks and operation of the "Software complex for measuring sportsmen's blows". Additionally, the advanced range of microelectronic sensors supports various electromechanical measurements, further complemented by a software package that handles data collection, analysis and storage from sports training. *Conclusions*: The application of this sophisticated software system to martial arts strike measurements, particularly in conjunction with a novel punching bag apparatus, may significantly improve our understanding of impact kinetics. This integrated approach is expected to produce accurate and reliable data on punch and kick power, enabling coaches and athletes to refine training strategies and boost their output.

Key words: *device, blow mannequin, theoretical foundations, blows, complex of software, accelerometric sensors, ADXL345, TaePunchBag app*

1. Introduction

The development of modern sports globally, along with performance benchmarks, indicates that sports achievements have reached significant levels. Consequently, professionals in the sports sector are tasked with inventing new, highly efficient technologies and conducting ongoing research to enhance current outcomes. With the aim of preparing athletes, who are actively training in Olympic sports in cities worldwide, for competition, state-level policy initiatives are emphasizing health improvement and increased sports participation. The authors argue that promoting sport is a necessary component of a good life. A "human right" is a justified claim or entitlement that belongs to every person, from birth until death, and which should be protected and respected by all persons [7]. The rapid rise of industrial civilization, capital, leisure, liberal democracies and mass media all contribute to sports' globalization and cultural pervasiveness [19].

As a result of the analysis of a number of various research studies across the globe have shown that training in single combat sports (such as boxing, taekwondo (WT), taekwondo (IT), kickboxing, karate (WKF) and hand-to-hand combat) necessitates the development of effective tools and methods by specialists to facilitate proper advancement. These tools include software packages for collecting, analysing and storing data from athletes' training. Despite considerable research and ongoing studies, an optimal technology for categorizing hand and foot strikes in these sports has yet to be es-

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tablished. Given this context, the need has arisen to develop a specialized punching bag with five distinct zones, taking into account different combat sports and establishing scientific validation for training and testing.

It is evident that more attention is being paid to issues of further development in this field because a specific policy is being implemented in the field of physical education and sports in Uzbekistan. The government's attention to sports has led to an increase in the number of people involved in sports, which, in turn, has led to the discovery of talented athletes. An increase in the number of athletes engaged in single-combat sports has led to an increase in competition among athletes. This indicates that specialists working in this field should approach the task of training high-quality athletes.

In combat sports, tournament results are determined by a number of interrelated factors such as motor characteristics, techniques, tactics, psychological features of the athletes and the refereeing method [8], [9], [20], [21], [24]. The impact force of punches or kicks on a punching bag is a critical component of special fitness [4], [22], [23]. Smith et al. [22] have proven that the force of the rear-hand punch is greater than the force of the lead-hand punch in boxers and that the power of the punching force is dependent on the athletes' skills. Similar assertions can be made regarding kicking force in taekwondo. In the literature related to this subject, only a limited number of studies have compared the punching and kicking forces between female and male athletes [14]. High performance in sports requires extensive technical skills, among other abilities. Particularly in combat sports, technique execution does not solely serve to reach a biomechanical goal, but rather has a tactical purpose [10]. Technique analysis in combat sports is based on a precise study of techniques such as punches and kicks. Each technique requires accurate execution of sequential actions in combination with correct posture and precise targeting to achieve maximum effectiveness [1].

Various systems to measure strike force have been discussed in literature, including water-filled heavy bag [16], strain gauge-based measuring systems [8] and an accelerometer-based measuring system [15]. Consisting of a punching bag with an embedded strain gauge, the BTS-3 boxing training simulator system [3] formerly utilised at the Institute of Sport in Warsaw did not fully meet the diagnostic expectations of boxing and taekwondo, however, Buśko was able to create a punching bag that meets the diagnostic requirements of boxing and taekwondo [3]. The main aim of this study was to design a new system to measure punching and kicking forces as well as reaction times in combat athletes. In addition, this study examined whether there were any intersex differences in the force of punches thrown by boxers and the kicking forces delivered by taekwondo athletes [3]. However, Buśko has developed a new punching bag that meets the requirements of sports, special shock mannequin devices for boxing, taekwondo (WT), taekwondo (IT), kickboxing, karate (WKF), and hand-to-hand combat sports and the 5-zone technology that describes the athlete's theoretical basis for hitting has not been created. The main goal of this study is to describe the methodological basis of using complex software for measuring strikes by martial arts with an innovative punching bag device and single combat sports (boxing, taekwondo (WT), taekwondo (IT), kickboxing, karate (WKF), the sport of hand-to-hand combat), and the creation of a boxing device with a wide range of sensors for the implementation of various electromechanical measurements, as well as the development of a software package for the collection, analysis and storage of data obtained during sports activities. Boxing, taekwondo (WT), taekwondo (IT), kickboxing, karate (WKF), and hand-to-hand combat were used to determine the power of blows. We have developed and implemented a methodical basis for using complex software to measure strikes in martial arts with an innovative punching bag device. We scientifically substantiate the results of this study. This innovative device is currently used in individual combat sports (boxing, taekwondo (WT), taekwondo (IT), kickboxing, karate (WKF) and hand-to-hand combat).

2. Materials and methods

2.1. Physical and technical characteristics of the device model

Martial artists often use punching and boxing bags to perform these striking techniques. However, these bags do not allow for an objective assessment of the strike force and its other characteristics. Modern microelectronics includes a wide range of sensors for various electromechanical measurements. For this reason, the task arises of equipping bags for practising punching, for example, a boxing bag with modern technical measuring instruments, developing techniques for converting the physical quantities measured by them into quantitative characteristics accepted in sports, calibrating measuring instruments, and developing a software package for collecting, analysing and storing data obtained during sports training.

The most important parameters for these purposes are the "strike force" and the deviation error from the designated strike point. Technically, the term "strike force" is inaccurate, because the theory of strike considers the moment of strike, which is defined as

$$S = \int_{t_0}^{t_1} F(t) * dt \,, \qquad (1)$$

where S is the moment of strike, $F(t)$ is the strike force, t_0 is the time at beginning of strike, and t_1 is the time at the ending of strike. To measure these parameters, the development of specialized measurement systems is underway. These systems range from sealed bags filled with water that measure pressure fluctuations, to solid training dummies equipped with spring force sensors, and even soft training dummies with accelerometric force measurement devices. Despite the diversity in the types of training dummies and the methods for measuring the forces generated by strikes on them, the most effective combination of dummy type and strike force measurement technique has yet to be determined. Consequently, research in this area is ongoing.

In accordance with the research plan, it was necessary to develop a training complex for striking sports capable of measuring the "strike force" and the coordinate of the strike point on the striking dummy, as well as evaluating the frequency or period of strikes on the dummy. The error in estimating the coordinates of the impact point was set to no more than 1/6 of the length of the mannequin. The striking dummy selected for research was a cylinder made of durable leatherette with a diameter of 45 cm and a length of 145 cm, filled with pieces of dense rubber approximately 5 mm thick, and measured in centimetres. The mannequin weighed 60 kg (Fig. 1).

To select a mathematical model for a dummy variable, it is important to know the physical and technical characteristics of the material. The most common parameter characterising a material in striking theory is the recovery coefficient, which is determined experimentally by dropping a ball of a material with a high recovery coefficient from a certain height onto the flat surface of the plate of the tested material and measuring the height at which the ball rebounds.

$$k = \sqrt{\frac{h_2}{h_1}} \,, \qquad (2)$$

where k is the recovery coefficient, h_1 denotes the ball drop height, and h_2 is the rebound height. However, such a measurement cannot be carried out for a cylindrical mannequin and a pendulum measurement method is used, the scheme of which is shown in Fig. 2.

A metal ball weighing 4.285 kg was dropped from point 1 from a height h_1, hit the mannequin at point 2, and bounced to point 3 at a distance L, which was measured. This distance corresponds to the height of the rebound h_2, which is equal to

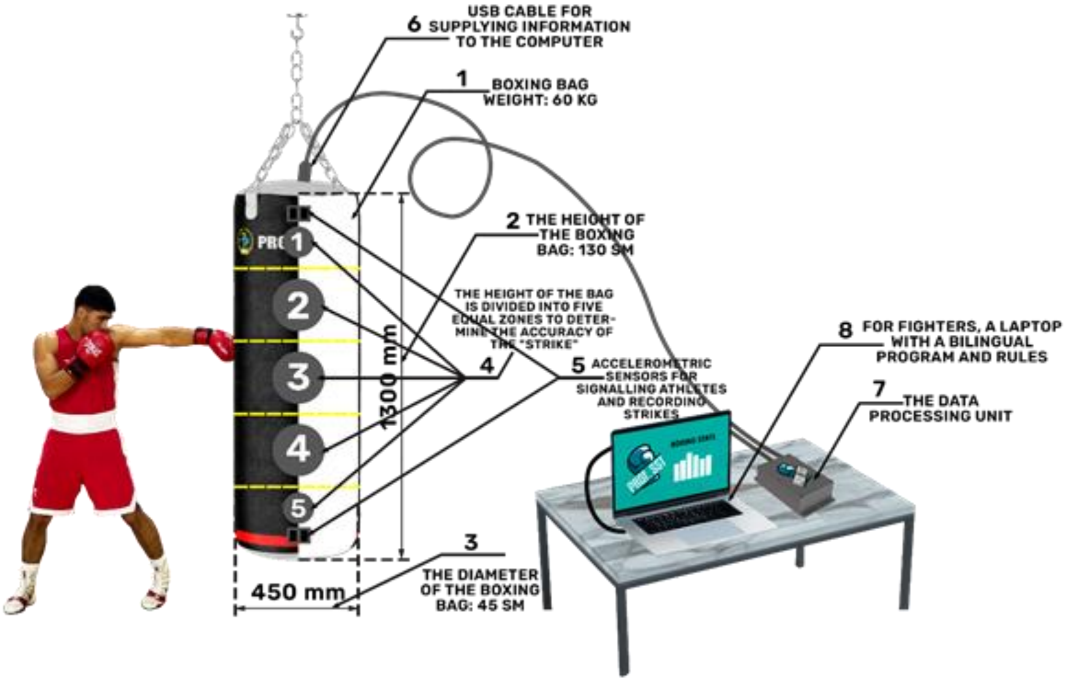

Fig. 1. Hardware and software package for measuring the strikes of martial artists

$$h_2 = h_1 * (1 - \cos(arc\sin(L / h_1))), \quad (3)$$

and the recovery factor is calculated using Eq. (2). In this case, h_1 = 2.3 m, L = 0.5 m, h_2 = 0.055 m and k = 0.15465. the velocity of the ball at the moment of impact is v_1 = 6.712 m/s, the velocity at the moment of rebound is v_2 = 1.0289 m/s, and the corresponding kinetic energies are A_1 = 96.584 J and A_2 = 2.91 J, respectively.

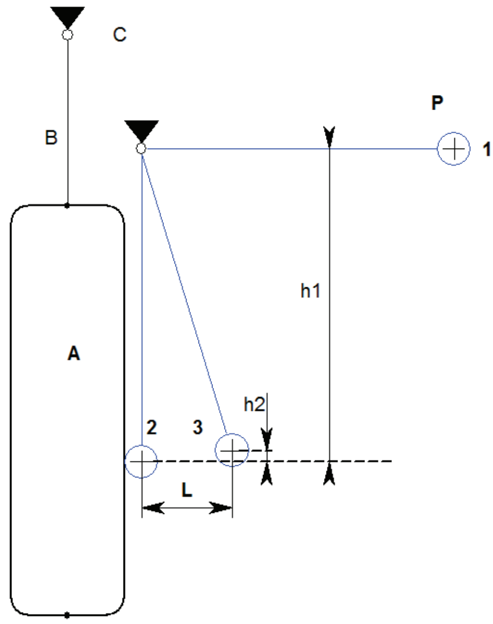

Fig. 2. The scheme of the pendulum measurement of the recovery coefficient. A – training mannequin, B – suspension cable, P – metal ball

Thus, for this striking dummy, the energy loss when struck by a metal ball was 97%, and the strike was practically inelastic; therefore, it was impossible to use a solid body model. In the theory of elastic-plastic strikes on beams, complex equations composed of dimensionless functions describing the mass and elastic and plastic properties of materials of this type are used to describe the motion of bodies.

$$\frac{\partial^4 \bar{y}^4}{\partial \bar{x}^4} + \pi^2 * \frac{\partial^2 \bar{y}}{\partial \bar{\tau}^2} = \bar{q} + \bar{p}, \quad (4)$$

where $\bar{x}$ is the dimensionless coordinate of the wave propagation direction, $\bar{y}$ is the transverse displacement function, π is a dimensionless function depending on the properties of the material, $\bar{\tau}$ is dimensionless time, $\bar{q}$ is the dimensionless function of the actual strike load, and $\bar{p}$ is the fictitious load function. Solutions of Eq. (4) are sought in the form of a superposition of general solutions in the form

$$y = f_1 * (k_1 * \bar{x} - c_1 * \bar{\tau}) + f_2 * (k_2 * \bar{x} + c_2 * \bar{\tau}), \quad (5)$$

where f_1 denotes the function of a wave propagating in the direction of $+x$, f_2 is the function of a wave propagating in the direction of $-x$, k, c – wave numbers and wave propagation velocities. The wave numbers k and velocities care functions of the parameters of the propagation medium and boundary conditions, as a result of which the relationship between the strike moment $\bar{q}$ and y'' the measured accelerations become nonlinear.

In the striking simulator being developed, accelerometers are installed on the lower and upper surfaces of the dummy to measure the modules of lateral accelerations. A pendulum with metal balls of various weights was used as a source of reference strikes, which allowed the performance of strikes at various points on the training dummy with precisely known values of shock pulses and impact energies. Several experiments were performed with the impact of pendulums of three different weighing balls at five points on the surface of a mannequin divided into five zones, as shown in Fig. 3. Strikes at points 1–5 are conducted by moving support D to the appropriate vertical position.

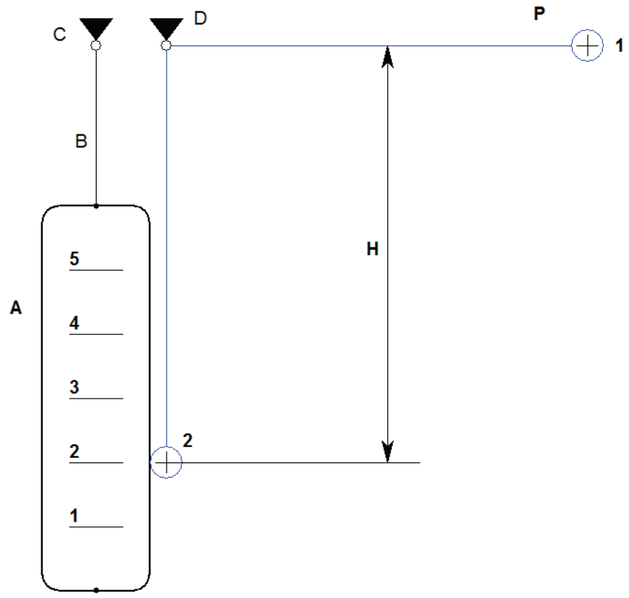

Fig. 3. The measurement scheme of the transverse acceleration module of the end face of the mannequin. A – mannequin, B – suspension cable, C – mannequin suspension support, D – pendulum suspension support, P – the metal ball of the pendulum

Fifteen strikes were performed, with five strikes each at Points 1, 3, and 5. Acceleration modulus diagrams of the upper and lower accelerometers averaged over five strikes are shown in Figs. 3–6. From the figures, considering the geometry shown in Fig. 4, it can be seen that

a) there are at least two different waves propagating in both directions;
b) there was a significant attenuation of waves during propagation in the mannequin body;
c) the amount of attenuation varies significantly in opposite directions.

To assess the degree of nonlinearity when using a solid-body model for a given striking simulator, the strike force and position of the strike point can be calculated using the formulas of the linear model:

$$F_r = 0.5 * m(a_t + a_b)\,, \qquad (6)$$

where F_r is the strike force, m is the dummy mass, a_t is the maximum acceleration value of the upper accelerometer, and a_b is the maximum acceleration value of the lower accelerometer.

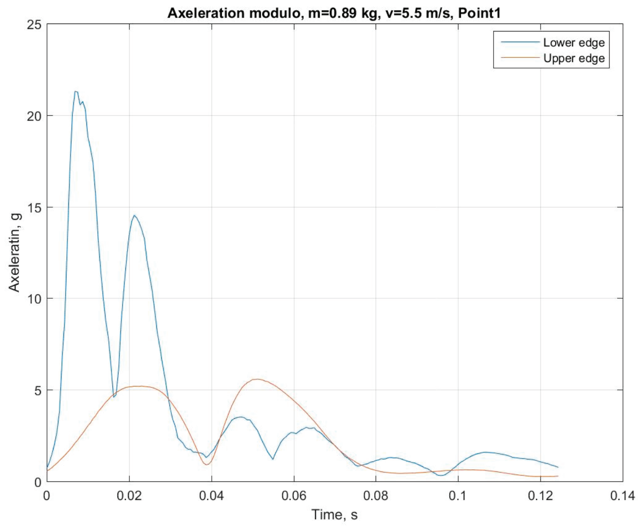

Fig. 4. Averaged time diagrams of acceleration modules of the lower and upper accelerometers, strike point No. 1

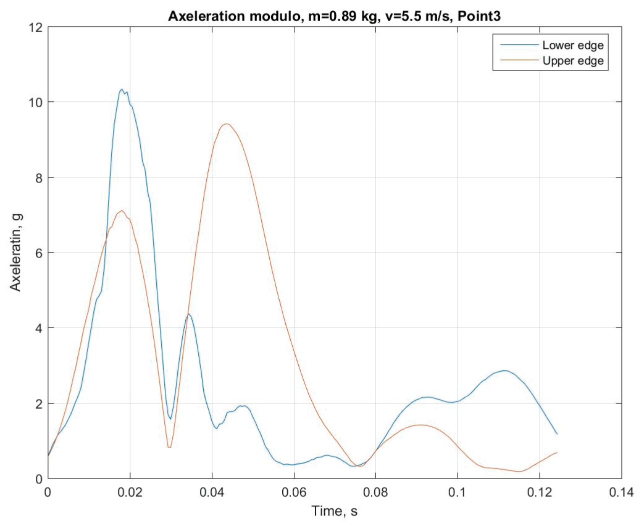

Fig. 5. Averaged time diagrams of acceleration modules of the lower and upper accelerometers, strike point No. 3

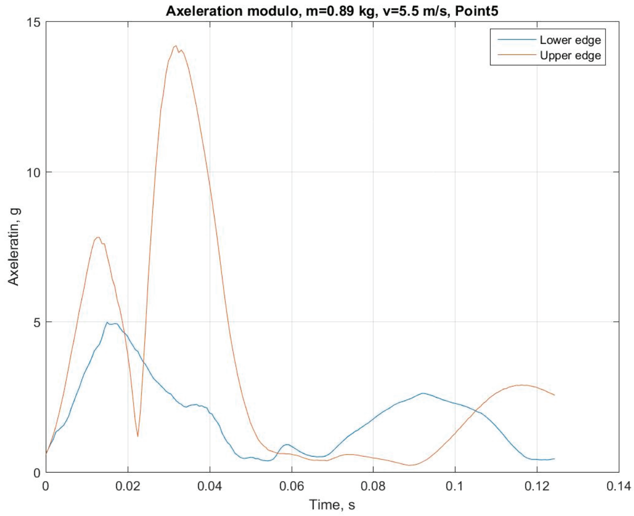

Fig. 6. Averaged time diagrams of acceleration modules of the lower and upper accelerometers, impact point No. 5

$$r = J_y * (a_b + a_t)/(l * F_r) \qquad (7)$$

where r is the measured distance from the impact point, J_y is the moment of inertia of the dummy relative to the central axis, and l is the length of the mannequin. The calculated values of the strike force and the positions of the strike points according to formulas (6) and (7) and the data shown in Figs. 3–5 are shown in Figs. 7 and 8.

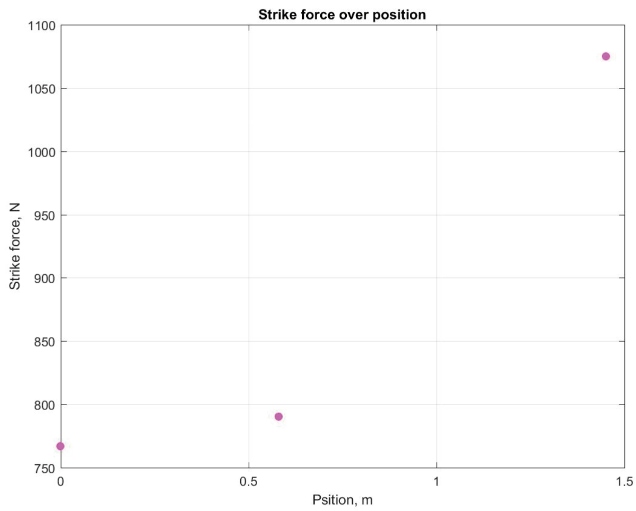

Fig. 7. Graphs of the strike force depending on the position of the strike point

The results of the experimental verification show that to correctly calculate the force and position of strikes for this simulator, it is necessary to use a model with strong attenuation of waves in the medium.

To address the challenge of swiftly and accurately assessing speed, strength capabilities, response to signals, and precision of strikes delivered by boxers and taekwondo practitioners, a hardware and software package was developed.

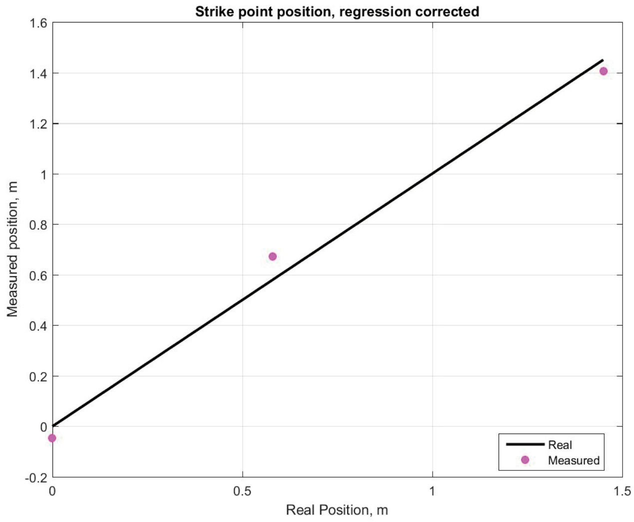

Fig. 8. A graph of the measured positions of the strike points depending on the actual position, corrected by linear regression

2.2. Functions of the hardware and software

1) High strike force without a signal ("max F without a signal");
2) High strike force with signals ("max F to signals");
3) The auto-signal. The signals have a high strike force of "max F on the signals" (comp);
4) The force of the strikes in 5 s (F), the total amount of "Upper force (F) in 5 seconds, ∑";
5) The total number of hits on both (right and left) is the total amount for 15 seconds;
6) Evaluation of explosive endurance in the "8s" test;
7) Assessment of the speed endurance of martial artists in the "40 s" test;
8) 8 seconds, the number of strikes "40 seconds", the average strike force and the total tonnage;
9) Three rounds of 3 min each, with a break of 1 min. Number of strikes in the 1st minute, force of strikes (F), and average force of strikes;
10) Three rounds of 2 min each with a break of 1 min. Number of strikes in the 1st minute, force of strikes (F), and average force of strikes;
11) Three rounds of 1.5 min each with a break of 1 min. Number of strikes in 45 s, force of strikes (F), and average force of strikes;
12) Three rounds of 1 min each with a break of 1 min. Number of strikes in 30 s, force of strikes (F), and average force of strikes;
13) Determination of special performance using a 2-min test. 20 s at moderate intensity and 10 s at high intensity. This was continued for 2 min;
14) The number of strikes in a series during 1st round;
15) The time between successive hits of the signal;
16) The number of precise strikes performed per round;
17) The power of precisely executed strikes on the signal.

The integrated hardware–software package includes taekwondo, boxing, kickboxing and karate, and, according to the classifications of strikes, determines the special motor preparedness of martial artists.

2.3. Functions of the software package

Determination of the explosive endurance of athletes

The test was performed in the fifth operating mode of the dynamometer. The length of the working segment was programmed to be 4 s. Duration of work: 8 s. After pressing the "Start" button (a bell will sound), the device was ready for testing. The recording of the number of strokes, running time and total tonnage was automatically activated by the athlete's first stroke. The athlete stood at an average distance from the dynamometric punching bag held by the assistant, and when ready, began to punch directly continuously with maximum force and frequency. Strikes were alternately performed with the left and right hands. After 4 s, you could hear a signal indicating that the job was half-completed. Simultaneously, information on the number of working segments appeared on the display. After the second beep, indicating the end of the second 4-s section of the work, information about the second half of the test appeared below, about the work done in a total of 8 seconds. The tonnage shown in both halves of the test, as well as their total values and the number of strokes, were recorded in the protocol. Based on the obtained values of athletes' maximum performance, the following indicators were calculated:

1) The work force in test W8 s in recalculation per 1 kg of the athlete's body weight in 1 second – W8 s = S8/P/8, where P is the boxer's body weight and S8 is the total tonnage of the work.
2) Coefficient of explosive tolerance, BEV = S2 × N2 / S1 × N1. Where S1 and S2 are the tonnages of the first and second halves of the test, and N1 and N2 are the numbers of strokes in the first and second halves of the test, respectively.
3) Index of explosive tolerance, IVV = W8 s × KVV.
4) Index of creatine phosphate work capacity = IVV × N8, where N8 is the number of hits in the "8 s"

test. The interpretation of these coefficients and indices was the same: the higher, the better. All calculations were based on the best (tonnage) attempt (out of two or three) [13].

Determination of speed endurance

This test was performed in the fifth operating mode of the dynamometer. The duration of the working segment was programmed to be 20 s. The duration of each task was 40 s. The athletes were instructed to perform direct blows of medium strength with a maximum frequency of 40 s. During the test, the force of the blows could be corrected; the force of the last blow was shown at the bottom of the screen and updated for every hit. At the end of the test, the results were subjected to the same mathematical calculations as in the previous test. Simultaneously, they calculated:

1) Per second, the work force in the test against the athlete's 1 kg body weight was W40 s = S40/P/40.
2) The coefficient of faster tolerance, KCB = S2 × N2/S1 × N1, where S2 and N2, and S1 and N1 are the number of hits in the second and first halves of the test, respectively.
3) Faster tolerance index, WIS = W40 s × SWR.
4) Glycolytic endurance index: GILV = WIS × N40/2,2, where 2.2 is a constant.
5) Integral work force index: IIMR = IVV + WSI.
6) Integral index of faster strength preparation: MISSP = BRAH + IGNALAR. When calculating the last two indices – IIMR and IISSP – IVV and IKFR indicators are obtained from the "8 s" test. The interpretation of all indicated indices and coefficients is the same as in the previous test; the larger the value, the better. As a rule, there is one valid attempt in the "40 s" test [13].

Complex functions in the program

1) High impact force without alarm "Maximum F without alarm".
2) High impact force on "Maximum F to Signals" signals.
3) Automatic alarm. Signals have high impact "Maximum F in signals" (comp.).
4) Hit force (F) in 5 seconds, total "High force (F) in 5 seconds, Σ".
5) The total number of hits on both sides (right and left) was within 15 s.
6) Assessment of explosion resistance in the "8 s" test.
7) Evaluation of speed endurance of athletes in the "40 seconds" test.
8) 8 seconds, the number of strikes "40 seconds", the average strike force and the total tonnage.
9) Three rounds of 3 minutes a 1-minute break. Number of blows in 1 min, force of blows (F), and average force of blows.
10) Two rounds of 1 minute a 1-minute break. Number of blows in 1 min, force of blows (F), and average force of blows.
11) Three rounds of 1.5 minutes, 1 min breaks. Number of blows in 45 s, force of blows (F), and average force of blows.
12) Three rounds of 1 minute with 1 minute break were performed. Number of blows in 30 seconds, force of blows (F), and average force of blows.
13) Determine special performance with a 2-minute test. Twenty s on average and 10 s at high intensity. This process required 2 min.
14) Number of shots in series during one round.
15) Time interval between successive beeps.
16) Number of exact shots in each round.
17) Power of properly executed shots.

The hardware–software package includes the following types of sports and, according to these classifications of blows, determines the special physical training of athletes (boxing, taekwondo WTF, taekwondo ITF, kickboxing, karate, and hand-to-hand combat).

Punches included in the program for the sport of boxing:

1) Straight punch (right).
2) Straight punch (left hand).
3) Side kick (right hand). 4) Side kick (left side).

Kicks included in the program for the sport of Taekwondo (WT):

1) Right leg (dole chagi).
2) Left leg (dole chagi).
3) Right leg (neryo chagi).
4) Left leg (neryo chagi).
5) Right leg (yop chagi).
6) Left leg (yop chagi).
7) Right leg (up huryo chagi).
8) Left leg (up-huryo chagi).
9) Right leg (ti chagi).
10) left leg (ti chagi).
11) Right foot (toran neryo chagi).
12) Left leg (toran neryo chagi).
13) Right leg (mon tule chagi).
14) Left leg (montule chagi).
15) Right leg (in dan ap chagi).
16) Left leg (in dan apchagi).
17) Right leg (in dan tolyo chagi).
18) Left leg (in dan tolyo chagi).
19) Free fight.

Blows included in the program for the sport of Taekwondo (IT):

Hand blows:

1) Straight punch (chjumok chjiguri).
2) Sharp punch (xan bon chjumok chjiguri).
3) Double straight punch (tu bon chjumok chjiguri).
4) Triple straight punch (sam bon chjumok chjiguri).
5) Punch with two fists at once (tu chjumok chjiguri).

Kick blows:

1) Straight kick (ap chagi).
2) Push with a straight leg (miro chagi).
3) Kick with the heel from above (nere chagi).
4) Kick with the heel from above from an angle (a nere chagi).
5) Heel kick from above with the inside of the foot (bakkat nere chagi).
6) Inward circular kick (dolle chagi).
7) Circular kick forward and upward (ap dolle chagi).
8) Oblique kick from an angle (pandal chagi).
9) A short swing of the foot in a small circle (bituro chagi).
10) Kick back (tvit chagi).
11) Vertical kick inwards (sevo an chagi).
12) Outward vertical kick (sevo bakkat chagi).
13) Whiplash kick (xure chagi).
14) Straight kick (momdolle xure chagi).
15) Circular kick (pal olligi).
16) Jumping round kick (tari xurigi).
17) Kicking 3 targets while jumping (yvio ap tora chagi).

Blows included in the kickboxing sport program:

Front kick:

1) Penetrating front kick.
2) Upward front kick.
3) Straight leg-upward kicks.
4) Front-leg kick.
5) Side-front kicks.
6) The heel front kick.
7) Hopping-front kicks.
8) Tilted heel-front kick.
9) Otward-tilted front kicks.
10) Inward-tilted front kicks.
11) Footblade front kick.
12) Oblique front kicks;
13) Instep angular front kick.
14) Switch front kicks.
15) Lift Kicks.
16) The front kick is dropped.
17) Drop twin-front kicks.

Sidekicks:

1) Penetrating sidekicks.
2) Upward-side kicks.
3) Front leg kicks.
4) Bent body-side kick.
5) Backside kicks.
6) Oblique back-side kicks.
7) Spin-back side kicks.
8) Drop-side kicks.

Roundhouse kicks:

1) Full roundhouse kick.
2) Small roundhouse kicks.
3) Front leg roundhouse kick.
4) Hopping the roundhouse kicks.
5) Oblique roundhouse kick.
6) Straight-legged roundhouse kicks.
7) Downward roundhouse kicks.
8) Bent-body long roundhouse kicks.
9) The 360 spin-back roundhouse kicks.
10) Heel roundhouse kick.
11) Dropping roundhouse kicks.
12) The rear leg drops the roundhouse kick.
13) The roundhouse kick was kneeled up.

Back kicks:

1) Penetrating back kick.
2) Short back kicks.
3) Spin back kicks.
4) Spin forward back kick.
5) Low back kicks.
6) Upper cut back kick.
7) Upward hook back kick.
8) Spin-forward hook back kick.
9) Downward back kicks.
10) The back ghost lifts the kick.
11) Drop back kick.
12) Drop hooking back kicks.
13) Dropping the overhead back kick.
14) Double-drop back kick.

Hook kicks:

1) Straight leg hook kick.
2) Hooked-hook kicks.
3) Front leg hook kick.
4) Oblique hook kick.
5) Half-pivot hook kick.
6) Downward hook kick.
7) Bent body hook kick.
8) Dropping the hook-kick.
9) The small heel back hook kick.

Crescent kicks:

1) Crescent kicks.
2) Front leg crescent kicks.
3) The crescent kicks outside.
4) Front leg outside the crescent kick.
5) The downward heel kicks.
6) The switch downward heel kick.
7) The 360-spin crescent kick.

Blows included in the program for the sport of karate (WKF):

Zuki – uchi vadza:

1) Kidzami – dzuki.
2) Gyaku – dzuki.
3) Chudanga.
4) Dzyodanga.
3) Uraken uchi.
4) Nagashi – dzuki.
5) Oy – dzuki.

Geri – vadza:

1) Mae – geri.
2) Chudanga.
3) Dzyodanga.
2) Mavashi – geri.
3) Ura mavashi geri.
4) Yoka – geri.
5) Ushira – geri.
6) Ushira mavashi geri.
7) Mikazuki – geri.
8) Ura makazuki geri.

Suri – ashi:

1) Suri – ashi mae geri.
2) Suri – ashi mavashi geri.
3) Suri – ashi ura mavashi geri.
4) Suri – ashi yoka geri.
5) Suri – ashi ura mikazuki geri.

Kicks included in hand-to-hand combat programs

Hand strikes used in the sport of hand-to-hand combat:

1) “Straight kick” to head with left hand.
2) “Straight kick” to head with right hand.
3) “Straight kick” to body with left hand.
4) “Straight kick” to body with right hand.
5) “Side kick” to head with left hand.
6) “Side kick” to head with right hand.
7) “Side kick” to body with right hand.
8) “Side kick” to body with right hand.
9) “Uppercut” with left hand.
10) “Uppercut” with right hand.
11) “Backfist” to the chin with the left hand.
12) “Backfist” to the chin with the right hand.

Kicks used in hand-to-hand combat:

13) “Straight kick” to the chin with the left leg.
14) “Straight kick” the chin with the right leg.
15) “Straight kick” to the body with left leg.
16) “Straight kick” to the body with right leg.
17) “Side kick” to head with left leg.
18) “Side kick” to head with right leg.
19) “Side kick” to body with left leg.
20) “Side kick” to body with right leg.
21) “Round kick” to the head with the left leg.
22) “Round kick” to the head with the right leg.
23) “Round kick” to the body with the left leg.
24) “Round kick” to the body with the right leg.
25) “Low kick” with the left leg.
26) “Low kick” with the right leg.

2.4. System operation

The instructor initiates the program on a computer and selects the required exercises from a list. Subsequently, an athlete is selected from the roster, and the “Start Training” button is activated. This action tog-

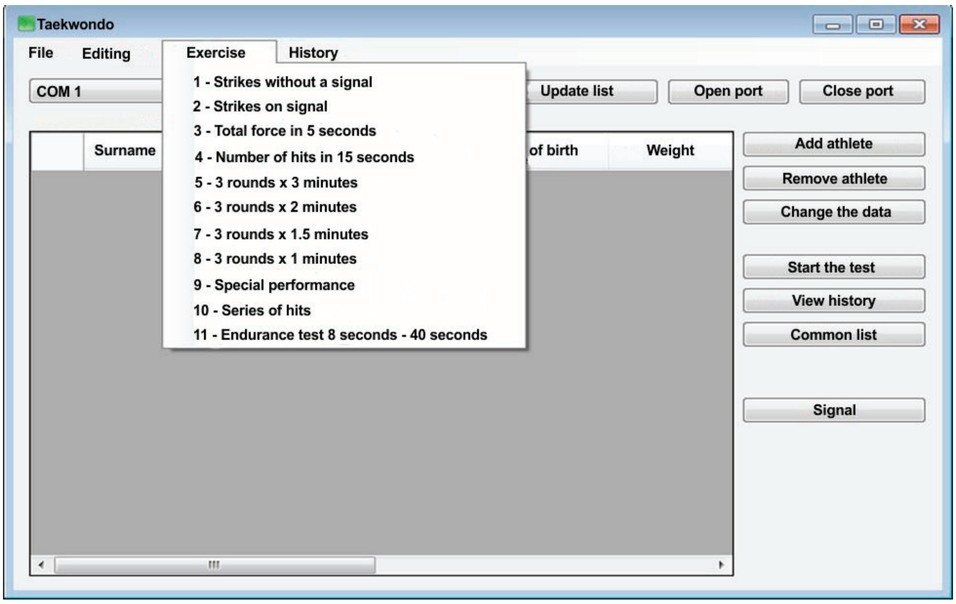

Fig. 9. TaePunchBag app

gles the data-processing unit and sensors into measurement mode. Should the athlete not be listed, they must be added prior to commencing the training session.

When the device enters the measurement mode, depending on the selected exercise, the microprocessor starts the timer, and the sensors start sounding and trigger an alarm. Each blow to the punching bag is recorded by a microprocessor, and its force and location (hit zone) are calculated. If necessary, the delay time from the moment of the signal is recorded, and the number of beats in the selected time interval is determined. In addition, the program provides the opportunity to send a signal manually when the teacher or trainer presses an appropriate button.

After the athlete completes the exercise, the microprocessor exits measurement mode, calculates the necessary parameters, and transmits the exercise results to a computer. The program enters the received data into the appropriate columns of the table. Subsequently, the instructor can select another athlete and perform the previously selected exercise again or select another exercise.

3. Results

The experimental results show that for this simulator, a model with strong wave attenuation in the medium should be used to correctly calculate the impact force and position.

In Figure 10, the average power of the punches (*F*) of the young boxers during the three rounds are shown. In all age groups, the average force of blows during three rounds is from 12.1 ± 1.5 kg to 15.9 ± 2.1 kg.

In the 2nd round, significant differences in punch force (*F*) were found among boxers aged 11–12 by 78% ($r < 0.05$) and by 82% among boxers aged 11–13. No

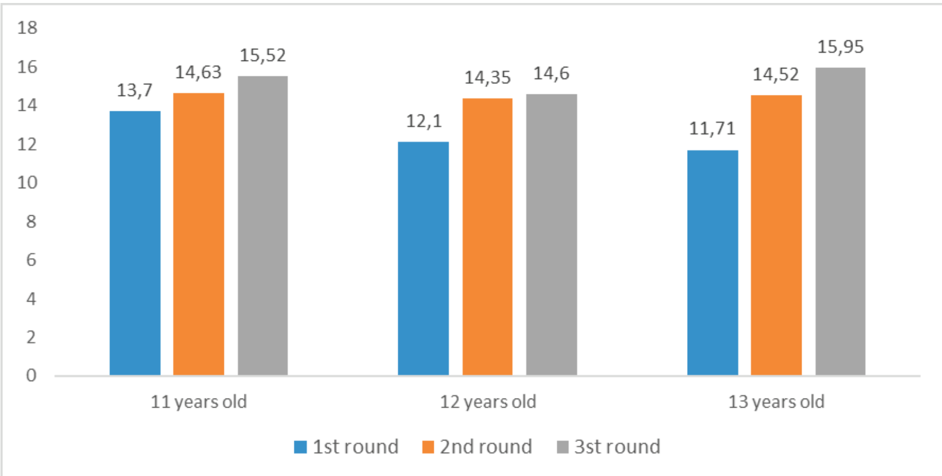

Fig. 10. The dynamics of the average blows power of 11–13 years old boxers during 3 rounds (Mean)

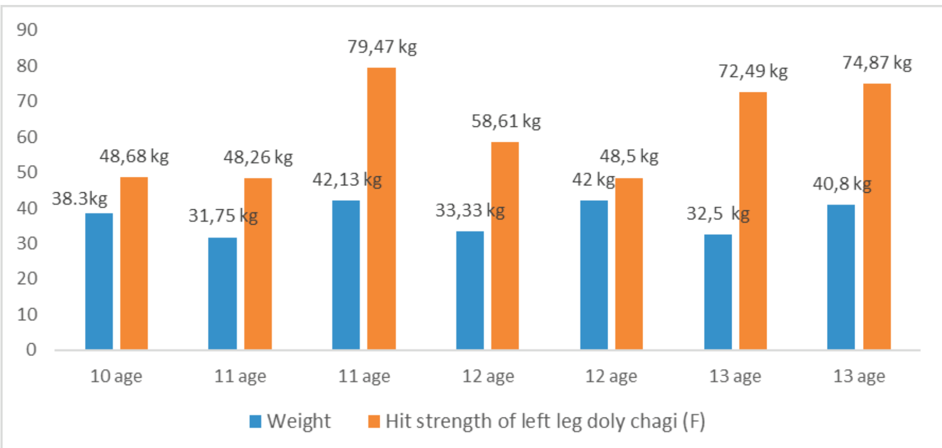

Fig. 11. Dynamics of special physical training of 10–13-year-old taekwondo players (Mean)

differences were found in the 12–13-year-old age groups.

The 3rd round is important for boxers in competitive matches, because the winner is determined based on the results of this round. The indicators of the power of blows of the boxers in the three age groups in the 3rd round decrease compared to the first round.

This reduction can be the basis for recognition, and special training for boxers of this age does not meet the requirements for conducting competitions.

According to the results, the dynamics of the special physical fitness indicators of teenage taekwondo players in the initial training stage were as follows: According to it, the absolute power of the left foot dolly shot of 10-year-old taekwondo players with an average weight of 29.15 kg was 61.99 kg, and the relative power was 61.99 kg. The minimum weight was 2.13 kg (Fig. 11).

The following information was provided in the experiments conducted to determine the technical training of 10–13-year-old martial arts students: to accomplish this task, a team of experts consisting of 12 highly qualified boxing specialists and 10 taekwondo specialists was formed.

Practical control tests were conducted to determine that the level of special physical fitness of 13-year-old athletes practising kickboxing in endurance was 2.28, and the index of creatine phosphate work capacity was 22.82. 33 kg level III athlete N. Djoraboev had higher results. It was found that the coefficient of explosive endurance is 2.32, the index of explosive endurance is 6.98, and the index of creatine phosphate work capacity is 69.87. It is clear from this that, despite the fact that this athlete has a small mass and is a level III athlete, he has higher physical qualities than his peers. Included by H. Tolashev, it was a sports school for children and teenagers.

In these controlled test exercises, the developmental levels of specific physical fitness indicators in young kickboxers were evaluated. The results of the kickboxers were recorded and the levels of development of the physical indicators were determined (Table 1).

Table 1. Indicators of 13-year-old kickboxers of special physical training in 30–45 kg

No.	S.N	Body weight	Sport category	CET	IET	CPWCI
1	O.S	35	II	–8.91	2.60	33.82
2	Sh.F	38	II	1.42	2.28	22.82
3	D.N	33	III	2.32	6.98	69.87
4	T.H	42	I	1.69	6.01	102.31
5	O.O	30	II	1.75	5.98	88.61
6	A.M	30	III	2.31	0.52	4.76
7	A.S	43	III	0.39	0.60	8.53
8	A.I	41	II	1.24	2.50	30.01
9	S.F	35	II	1.83	2.90	26.18

CET – coefficient of explosive tolerance, IET – index of explosive tolerance, ICPWC – index of creatine phosphate work capacity, CFT – coefficient of faster tolerance, IFT – index of faster tolerance, GEI – glycolytic endurance index, IWFI – integral work force index, IIFSP – integral index of faster strength preparation.

Control tests were conducted to determine the level of special physical training required for 13-year-old athletes engaged in hands-to-hand combat sports in sports schools (Fig. 12).

The control test exercises consisted of hand and leg kicks, typical of hand-to-hand combat, through which it was possible to assess the level of physical fitness of young hand-to-hand combatants.

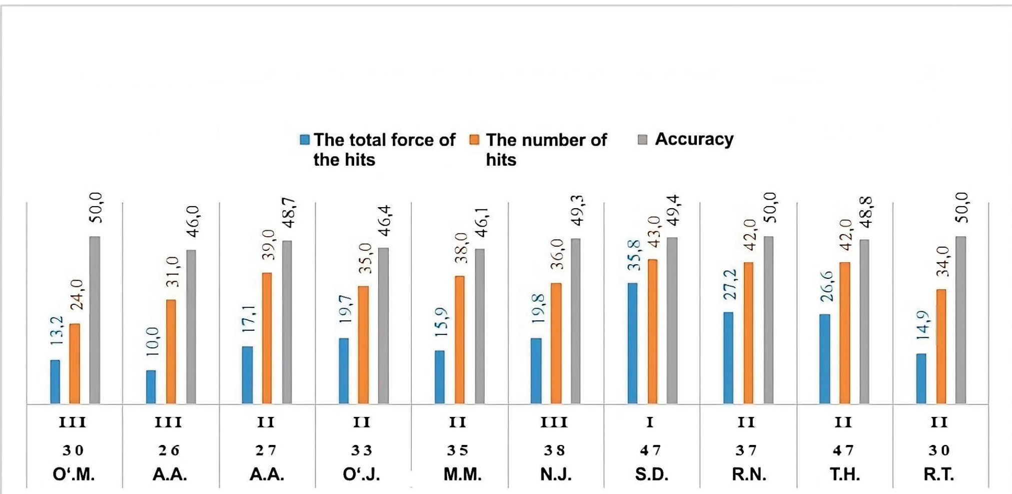

Fig. 12. Indicators of special physical fitness of 13-year-old the sport of hand-to-hand combat

4. Discussion

The main purpose of this study is to describe the design of a striking dummy and the theoretical foundations of martial arts strikes (boxing, taekwondo (WT), taekwondo (IT), kickboxing, karate (WKF), and hand-to-hand combat), the creation of a boxing device with a wide range of sensors for the implementation of various electromechanical measurements, and the development of a software package for the collection, analysis, and storage of data obtained during sports activities. In addition, the strengths of the blows were selected for boxing, taekwondo (WT), taekwondo (IT), kickboxing, karate (WKF), and hands-to-hand combat. Recent advances in technology have led to the more frequent integration of inertial sensor devices into sporting environments. The device concept, design, construction, calibration, and preliminary tests conducted by amateur athletes are presented to explain the possible applications of such devices in research and boxer training [5]. In the literature, various methods to measure the punching and kicking forces can be found, along with very diverse force values obtained [2], [6], [12], [15], [17].

Using a water-filled heavy bag, Pieter and Pieter [17] recorded kick forces ranging from 461.8 ± 100.7 N to 661.9 ± 52.7 N. Balius [2] reported mean impact force of nearly 2130 N, while Conkel et al. [6], who used piezoelectric film, measured impact forces up to 470 N. Falco et al. [8] measured the force of Bandal Chagi kicks using piezoelectric pressure sensors mounted on a boxing mannequin and recorded maximal forces of 2089.8 ± 634.7 N with the highest force being 3482 N. On the other hand, Pędzich et al. [16] recorded kick forces on a force plate up to 9015 N. The impact forces of delivered kicks were reported at a broad range of 382 N to 9015 N and depended on the measuring methods adopted and the type of punches and kicks performed. In boxers, the recorded punching forces ranged from 1990 N to 4741 N, Smith et al. [22] established that the force of a straight rear-hand punch equalled 4800 ± 227 N among elite boxers, 3722 ± 133 N in the intermediate group, and 2381 ± 116 N among novices.

Similarly, the punching force for a lead hand were, respectively, 2847 ± 225 N, 2283 ± 126 N, and 1604 ± 97 N. The maximum striking force recorded by Karpiłowski et al. [12] was 2697 N. In our study, the use of acceleration and angular velocity transducers to measure the movement of a dynamometric punching bag enabled the construction of a dynamometric punching bag with a considerably longer cylindrical striking surface (L = 1.8 m) than the previously used BTS-3 punching bag (L = 0.5 m) with an embedded strain gauge described in the study by Karpiłowski et al. [12]. The use of four signal diodes enabled tests in which strikes could be executed with both the upper and lower limbs at different heights permitted in a given sports discipline.

The punching forces recorded with our punching bag having an embedded accelerometer oscillated between 500 N and 2276 N among the group of boxers; the kick forces (Dwit Chagi) among taekwondo athletes ranged from 1576 N to 5315 N. The force values recorded for boxers corresponded to the results obtained by Karpiłowski [12] and Smith et al. [22] for novice athletes. Smith et al. established that the force of a straight rear hand punch was greater than that of a straight punch thrown by a lead hand. The results obtained in this study correspond with the data collected by Smith et al. Furthermore, the results recorded with our new punching bag with an embedded accelerometer were similar to the results produced by the BTS-3 strain-gauge-based punching bag, thus enabling a comparison of the results obtained in earlier studies using a punching bag with an embedded strain gauge. Li et al. [14] observed roundhouse kicks with forces of 2940 N and 2401 N for males and females, respectively. In our study, intersex differences were observed among taekwondo athletes for both types of kicks delivered with the rear and lead legs, which is consistent with the results obtained by Li et al. [14].

From our analysis of many scientific and research works, we found that it is necessary to develop an excellent software complex for collecting, analysing, and storing data obtained from the results of special physical training for athletes in martial arts training. We developed and implemented a set of software hardware to measure martial arts strikes, designed to solve this problem. To measure the blows of martial arts, we have improved the complex of software hardware divided into 5 zones, as well as we have conducted experiments on boxing, taekwondo (WT), taekwondo (IT), kickboxing, karate (WKF), the sport of hand-to-hand combat and we put the results into practice. We also developed and implemented a methodological basis for using the software complex to measure blows in martial arts. We scientifically substantiate the results of this study. This innovative device is currently used in martial arts.

5. Conclusions

As a result of this project, studies on the processes of shock wave propagation in an elastic – plastic cylindrical mannequin used for training in striking sports were conducted.

Three mathematical models were developed to calculate the impact moments and the coordinates of the impact points on the dummy.

Schematic diagrams of all the blocks of a complex simulator for measuring power and time parameters in various impact sports were developed, and the blocks were manufactured and tested.

Software for accelerometer module processors and data processing units was developed and debugged, as well as a simulator control program and measurement data storage.

Experiments were conducted to evaluate the parameters of the mannequin material and calibrate the simulator, which made it possible to obtain acceptable measurement errors for the striking moments, point coordinates, and time parameters of a series of strikes.

The developed hardware and software complex, in accordance with agreement no. 4762559, was transferred for pilot testing to the Uzbek State University of Physical Education and Sports and is currently in operation.

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