A Development and manufacture of A multi-objective platform for measurement and analysis of dynamic force

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Abstract: The research aims to develop the force platform as a first product through an engineering design characterized by the flexibility of the metal and its small size. This is one of the challenges that requires engineering ingenuity. It also aims to show the quantum physical relationship between force and acceleration. It provides a quantitative measurement of the body's interaction with the external environment The researcher reached to the manufacture a force platform using high-sensitivity and high-speed sensors. Through it, he applied practical applications to [4] athletes in standing, walking, running, and vertical jumping. The device presented results with quantitative differences, according to the nature of Technic each movement. To validated the accuracy of the results, the researcher conducted a calibration of the factory device through the non-linear model relationship between force in kilograms and resistance with electric voltages by using weights starting from [6.25 kg to 86.25 kg] and the device provided satisfactory results

Keywords: *(forceplatform,sensors, validation calibration,resistance ,electric voltage)*

Introduction and research problem:

The enhancement of positive aspects of skill or physical performance and reduction of aspects that are inconsistent with the nature of performance in the sports field are among the things that have occupied the minds of technical scientists to address weaknesses and to identify and invest the facts, Whether they are external or internal influences, and use them to develop the achievement, In order attain to accurate dynamic quantitative measurements, devices with little errors are designed to obtain accurate numerical data. The tendency of scientists to the sports field was an effective contribution, as the current achievements are miracles in comparison with the previous achievements.[1-1]

Force Platforms provide critical data for biomechanical analysis because they measure the interaction between the subject and the environment. If the subject is in contact with the floor, the joint forces, moments and powers have no physical meaning unless the reaction force data are included in the analysis.[4-6]

The importance of developing a platform for measuring force lies in showing the qualitative or quantitative physical relationships among force, acceleration, velocity and displacement, as well as providing illustrative drawings of the applications of biomechanics in sport movements such as walking, running, jumping and vertical jumping.[9-306]

Research on the development of force platforms is an objective study that relies on honesty, consistency and objectivity of results based on the accuracy of the calibration used, which the researcher cannot interfere with or influence the results obtained. Everyone, without exception, needs a deeper understanding of the developing and designing force platforms as well as the scientific basis on which those platforms are built; which helps to understand how and why movement works in the world of sport from a physical [Mechanical], perspective on the other hand, curiosity and ambition for development teach us as researchers observation, analysis, and improvement of performance, as well as a good handling of sports tools and scientific equipment's intended for measurement.

Research problem :-

Force is a word used to express how one object affects another. AL lording to Newton's third law, the effect of this force on the first body always has an equal and opposite reaction in its magnitude, and affects the second body, by changing its state of movement or a state of quietness or causing a change in its natural condition. this force is measured by the its extent of changes in an object. and indirect methods depend on measuring the distance and velocity, and acceleration, of which the magnitude of those variables is directly proportional to the magnitude of the force. The direct method depends on changing the shape of the body, as the amount of change is directly proportional to the amount of force created for it. Some direct methods depend on the mechanical or hydraulic balance of forces, Which depending on the transfer of the force to be measured by a liquid or gas to a device that measures its amount., Another direct method relies on measuring the force stress of objects. The researcher will rely on the second direct method, as it relies on high-sensitivity and high-speed sensors to read and record time-varying strengths such as [strain gauge or piezoelectric], The results are also accurate and easy to calibrate. The researcher will also try to move from the design of the current rigid traditional platforms to an engineering design characterized by the flexibility of the metal used and the ability to adapt to different situations in sports movements.

The transition from engineering designs that are rigid and large-scale to flexible and compact designs is a challenge that needs engineering ingenuity. The main reason behind this shift is to solve difficult problems that traditional large-scale rigid force measurement platforms. Cannot solve. One of these problems is the measurement and analysis of the dynamic force of each foot separately; such as the starting position of swimming 100 meter sprint, where it is difficult to measure this force through traditional and rigid platforms, as well as tracking the stage of the double support foot at each step during the analysis of the walking phases. The current design also helps researchers to study dynamic equilibrium by tracking movement during a long period of time. By calculating both the amount of force and resistance as two basic variables in identifying the dominant lever type with movement, a dynamic balance can be studied, Therefore, this is the first aspect of the research problem that prompted the researcher to develop the force platform through a small-sized engineering design characterized by flexibility of the metal used for each foot separately, which is appropriate for all kinetic situations.

The second aspect of the research problem is to verify the accuracy of calibration. Many studies such as Study No.[2 , 9 , 10], recommend verifying the accuracy of calibration of force platforms by following methods that give accurate numerical data and the lowest possible level of error, Therefore, after completing the design of the force platform, the researcher aims to make accurate calibration through the non-linear model relationship between force in kilograms and resistance in units of electric voltages.

The third aspect of the research problem is embodied in the material costs facing faculties of physical education in general and the factor of biomechanics laboratories in particular, And related to the purchase of commercial scientific devices for example. Study No. [2,3] indicates that the cost of the force platform ranges from $ 10,000 - $ 30,000.Due to the in this regard, the researcher conducted a survey study aimed at knowing the availability of the force platform within the biomechanics laboratories in the faculties of physical education in Egypt, importance of the above mentioned force platform uses there are 23 faculties of physical education in 2019 [23] in Egypt, of which the force platforms within the biomechanics laboratories are available at a rate of 21.74%, which is small compared to the total number of colleges that do not have strength platforms that reach 78.26%, The researcher attributes the lack of the force platform to its high cost. Thus, the researcher aims to conduct a flexible homemade engineering design which matches the international prices and encourages the local product and also in line with the strategic plan of the country.

Research aim: -

The research aims to "A Development and manufacture of A multi-objective platform for measurement and analysis of dynamic force"

Search questions: -

- Can the analog signal be captured and converted into a digital signal in light of the optimized engineering design of the target force platform?
- How can the accuracy of the calibration of the target engineering design be validated in light of the typical non-linear relationship between force and resistance?
- Are there any quantitative differences for the reaction force magnitude curve with time for standing, walking, running, vertical jump of the proposed force platform?

Search procedures :

Research Methodology :

- The researcher used the descriptive approach (case study) due to its relevance to the nature and treatment of the research problem .the approach is concerned with describing the studied phenomenon in an accurate manner, using a quantitatively or qualitatively. Method the quantitative method gives a numerical description that clarifies this phenomenon and shows the degree of its association with other phenomena.
- Use the experimental approach, with the aim of conducting practical applications, the platform for measuring force, to ensure the accuracy of the results of the device.

The research sample :

The research sample was chosen in an intentional way, which was represented in [4] athletes, to conduct applications on the force platform proposed by the researcher, and to identify the quantitative differences in the amounts of reaction forces with time for standing, walking, running, vertical jumping.

Statistical characterization of the research sample:

The researcher conducted the torsional and the flatness coefficients of the individuals of the research sample before conducting applications on the target force platform, in order to indicate the homogeneity of the members of the research sample to ensure moderation in the search variables that may affect the results of the application, and came as follows:

Table [1]

Average, standard deviation, coefficient of torsion and flatness of the variable (age, length, weight) of the sample in question . N [4]

N	variables	M. unit	average	St .dev	Co .To	flatness
1	Age	Year	21	± 1.4	1.4	1.5
2	length	M / Cm	1.74	± 0.04	1.3	2.48
3	weight	Kg	73.25	± 3.00	0.37	-3.9

Table (1) shows that the value of the skewness coefficient ranges between [0.37: 1.4] which is less than twice the standard error of the torsion coefficient. The value of the Kurt coefficient ranged between [-3.9: 2.48], which is less than twice the standard error of the Flatulence coefficient, which indicates the moderate distribution of the sample.

Data collection tools:

- Solid work Program.

- Graduated weights starting from [6.25 kg to 86.25 kg] are used to calibrate the force platform proposed by the researcher.
- Medical scale for measuring using [kg].
- Rust-meter for measuring length using [M/cm].
- The electrical signal control and calibration device [microcontroller].

The scientific basis for developing the force platform:

The process of designing any device which perform a specific function includes a number of stages starting with a description of the problem, which includes the accurate description of the forces acting, their direction and impact points, then the stresses and reactions resulting from these forces; finally selecting identifying to the different parts and shape, which ensures the bearing of Influence forces without a breakdown of the designed device.

Therefore, the scientific basis for the designed device depends on measuring the ground reaction force, which is one of the main variables in many sports, and also in general movement analysis such as (gait analysis). To measure these forces, the following engineering components were used: -

Force - sensing resistor [FSR]:

The FSR is a force sensor that uses a variable resistance which change according to the applied force on a specific area. It is a Customized and available design and easy to made. The two sensors contact with two electrode surfaces with neglected resistance of very low value. However, it is an easily used and in widely application, Fig.1.

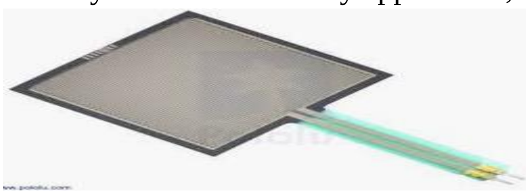


Fig. 1. force - sensing resistor

Design:

For the experiment purpose, two electrodes are designed to measure the average applied force on the sensor area. A rectangular sensor with dimension of 15*12 Cm ,The thickness is 0.2 Cm is used to force platform for the force calculation fig .2 – A . B.The two electrodes are designed with the same dimension and a flexible PCB are made for that task. A protection layer of booth cupper and flexible plastic is inserted above the two electrodes to increase the lifetime and provide more mechanical stress resistance during test. A polymer of non-linear force VS resistance characteristic is used which is essentially a carbonic bond crystal structure with 4 covalent bonds with adjacent atoms. Fiber is a very good choice despite of its high cost. consider compared with other material but due to the chemical and stress and strain stability of fiber it is provide a good material to be use in dynamic application.

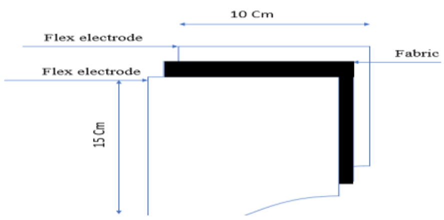


Fig .2-A. scale force platform sensor for the right and left foot

Fig.2-B. is prototype of the force platform for the right and left foot

Statistical treatments:

- Average
- standard deviation
- coefficient of torsion
- Flatness

Presentation and interpretation of results: - Second: The first question states: Can the analog signal be captured and converted into a digital signal in light of the optimized engineering design of the target force platform?

In purpose to record the data and analysis the signal Arduino Uno is used as micro controller. A voltage divider technique with 324 Ohm resistance is used for analog signal read. The Analog signal are scaled to 1023=2^10 due to the 10 bit microcontroller. Vcc= 5 volt is applied and producing a resolution of 5/1024= 4.8 mV between each level. The next fig. 3. shows the Arduino connection and voltage divider circuit.

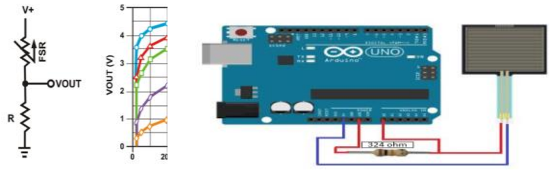


Fig.3.Arduino development board and electronic control

The signal is scaled to 5 volt scale by dividing the analog value by 1023 and multiply by 5 to present for 5 scale voltage. The choice of 324 ohm resistance is based on microcontroller limitation current not accessed 10 mA at full loading. The FSR value resistance can be calculated using the equation written down.

$$FSR = 324 * \left(\frac{Vcc}{Vout} - 1\right) \quad (1)$$

Then the equation estimated from the calibration is used to estimate the force value. 600 Hz are record per second during the test. Given the large numbers, which are difficult to display in a table, the researcher suffices to display the estimated force curve, and figures .4. 5.6. show this.

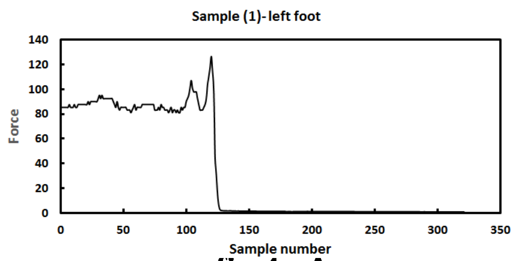


fig.4 –A

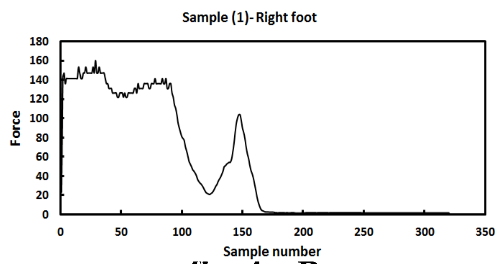


fig .4 – B

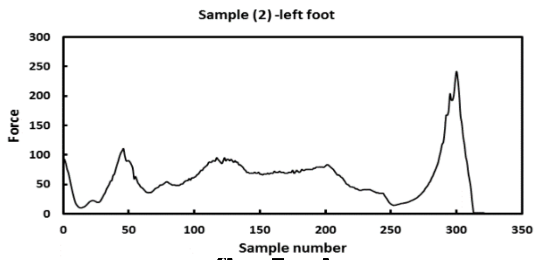


fig .5– A

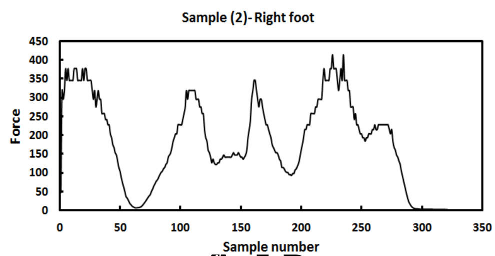


fig.5-B

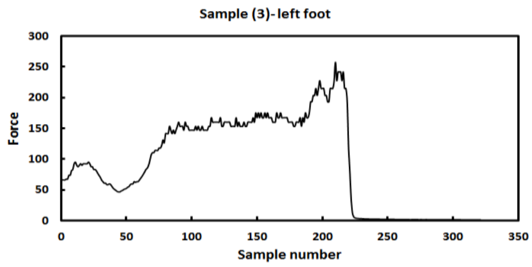


fig .6 – A

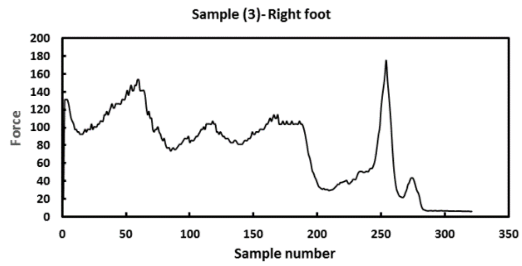


Fig .6-B

Fig. 4.5. 6. show the estimated force curve as a result of applying the mathematical equation for three experimental samples of platform No. (1) and (2) for the right foot and the left foot.

Second: The second question states: How can the accuracy of the calibration of the target engineering design be validated in light of the typical non-linear relationship between force and resistance?

Calibration of measuring devices is among the most important concepts upon which scientific measurement is built, as the measurement process is not in the precise form that meets the requirements of quality in a time characterized by globalization and intense competition between countries unless it accompanies the result of the measurement specifically for the error rate present in the designed devices, and this is through a series of measurements that ensure the device reference by means of accurate calibration of the devices. The researcher calibrated the current device according to the following relationship.

FSR Characteristics and calibration:

A) FSR characteristics.

The characteristic of the FSR sensor is mostly not linear with the resistance and linear with conductance. Most studies .4.11.13.14.use the nonlinear model of the resistance as standard. The basic equation N .2 form is presented below [11]:

$$\textbf{(2)} \qquad F = \left(\frac{A}{R}\right)^{\frac{1}{B}}$$

This equation can be shown by the next figure.7. As it's shown in the curve, the value of the resistance is very high at low force applied and decreases rapidly with increasing the applied force, three important point.

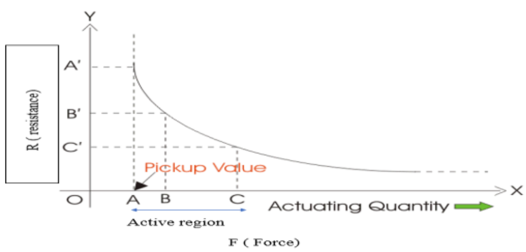


Fig.7. the active operating area

A, B and C are shown in the curve. The slope before the point A has a very large value = info ' which means that when only small amount of force is applied the force changes with very large value and for that this region cannot be used in working. on the other hand, the slope after the point C approximately equals to zero, and this very large change in the applied force will cause only a small change in the resistance value. thus, this region can not also be used due to the mentioned above. The active or effective operation region is the region between the point A and C.

B) Calibration:

The calibration is made with standard weight start from 6.25 Kg to the value of 86.25 Kg fig.8. and the resistance characteristics are drawn as shown for the both sensor in the next table 2.and fig.9.

Fig.8. shows the method of calibration through the real graded weights and finding the relationship.

Table [2]

Average force values in kilograms and their relationship to the average resistance amounts in volts for the force platform for the right and left foot

N	R. foot platform		L. foot platform	
	M.force.Kg	M.Resistance.ohm	M.force.Kg	M.Resistance.ohm
1	6.25	28.61	6.25	146.14
2	11.25	21.26	11.25	96.62
3	16.25	14.22	16.25	63.21
4	21.25	10.80	21.25	54.37
5	26.25	8.78	26.25	46.34
6	31.25	7.78	31.25	37.45
7	36.25	6.46	36.25	35.10
8	41.25	5.80	41.25	30.87
9	46.25	5.15	46.25	28.23
10	51.25	4.82	51.25	22.71
11	56.25	4.50	56.25	21.98
12	61.25	4.17	61.25	20.90
13	66.25	3.85	66.25	17.70
14	71.25	3.52	71.25	17.35
15	76.25	3.20	76.25	17.00
16	81.25	2.88	81.25	16.30
17	86.25	2.55	86.25	15.60

Table.2 shows in that the resistance amount in volts varies according to the amount of force applied kilogram on the force platform No.1.2. proposed for the right foot and the left foot.

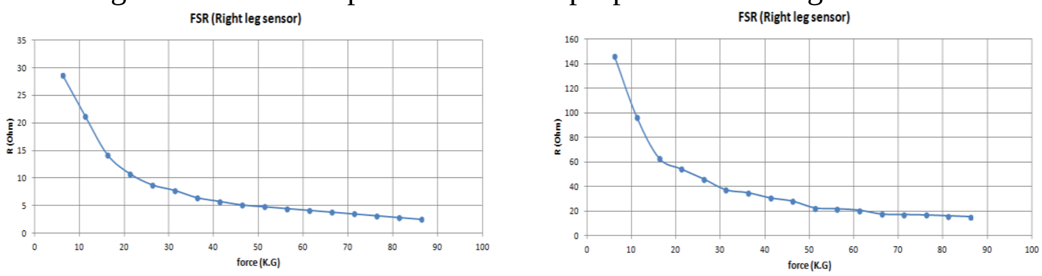


Fig.9. curve of the non-linear typical relationship between the forces and the amount of resistance in volts.

Using least square technique to estimate each sensor characteristics is the solution to present the sensor characteristics.

$$\textbf{(3)} \quad F = \left(\frac{186.7440}{R}\right)^{1.06887} \quad \textbf{Right leg sensor}$$

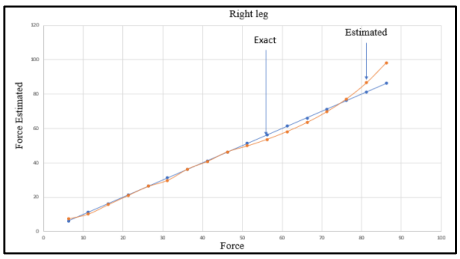
$$\textbf{(4)} \quad F = \left(\frac{797.24}{R}\right)^{1.12676} \quad \textbf{Left leg sensor}$$

A comparison between the estimated equation and the test point are shown in the next table 3.and fig.10.

Table (3)
Average force in kilograms and their relationship to the average estimated force amounts for the force platform of the right and left foot

N	R. foot platform		L. foot platform	
	M.force.Kg	M. Estimated force	M.force.Kg	M.Estimated force
1	6.25	7.43	6.25	6.76
2	11.25	10.20	11.25	10.78
3	16.25	15.69	16.25	17.39
4	21.25	21.04	21.25	20.61
5	26.25	26.24	26.25	24.68
6	31.25	29.86	31.25	31.37
7	36.25	36.44	36.25	33.74
8	41.25	40.87	41.25	38.99
9	46.25	46.45	46.25	43.12
10	51.25	49.82	51.25	55.12
11	56.25	53.69	56.25	57.17
12	61.25	58.18	61.25	60.51
13	66.25	63.45	66.25	72.97
14	71.25	69.70	71.25	74.64
15	76.25	77.26	76.25	76.38
16	81.25	86.56	81.25	80.09
17	86.25	98.28	86.25	84.13

Table.3. shows that the researcher was able to find the relationship between the average force in kilograms and the average estimated force by applying the mathematical equation N.3.4. which shows the approximation of the real force amounts (kg) with the theoretical quantities the result of applying the mathematical equation.



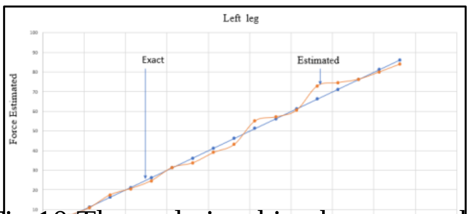


Fig.10.The relationship between the real and estimated forces of the mathematical equation.

to find the coefficient of the equation using the calibration data , the RMS error value is minimized and such that the cross ponding equation parameters are estimated which cross ponding to the lowest error value. The values in a table [3] indicate what the researcher reached by reducing the error (RMS) between the calibrated force in kilograms and the estimated force resulting from applying the mathematical equation.

Both sensors show stable and low error until 50 KG applied force after 80 Kg the error increases rapidly and in-accurate result will occur. Due to this, maximum operation range is 80 Kg for low error for the all measurement range the RMS Error is 4,07% for right leg sensor and 2.88% for left leg sensor. In that range value the resistance value approximately is (28-150) to (2-15) ohm for Right and left leg sensor. This information is very important in the net hard ware design section.

<u>**Third: The third question states:**</u> Are there any quantitative differences for the reaction force magnitude curve with time for standing, walking, running, vertical jump) of the proposed force platform?

First: The ground reaction force curve results from the walking and running test of the force platform.1. and.2. for the left and right foot, which was developed by the researcher .feg.11-A.B.

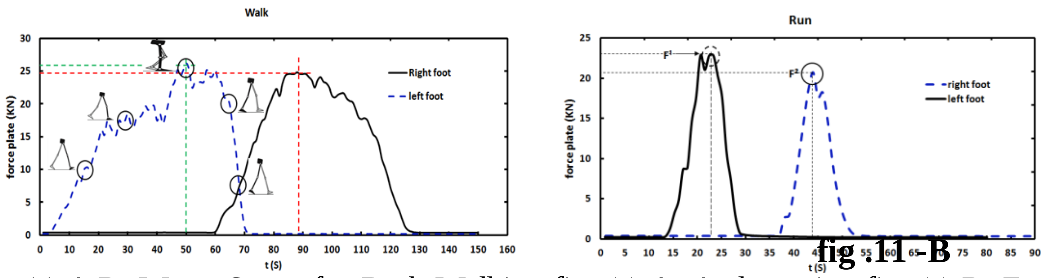
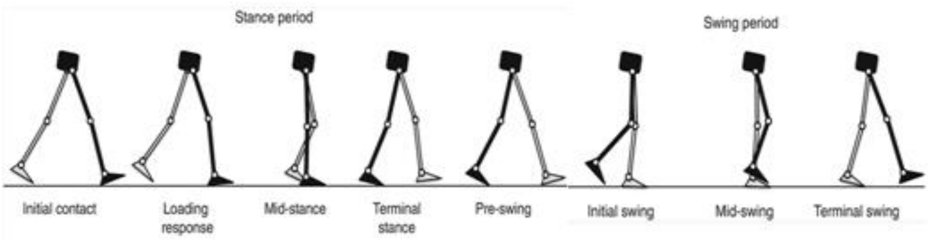


Fig. 11-A.B. Wavy Curve for Both Walking fig. 11-A. And running fig. 11-B. For platform No. 1 for the left foot, platform No. 2 for the right foot, and the time differences below the curve between walking fig.12. and running.

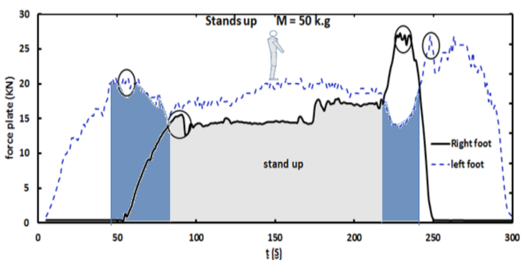


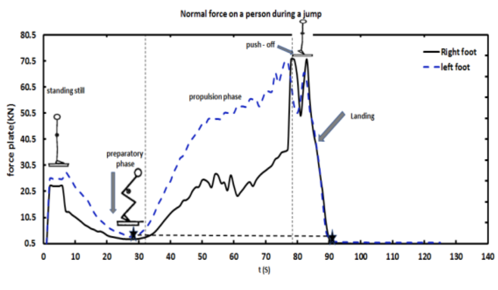
The researcher has conducted some tests on the force platform for four different movements; standing, walking, running, vertical jumping, to know the ability of the platform to show the quantitative differences between them, and to demonstrate the reality of the results obtained for these movements shown in curves No.11-A.B.From the force platform, the researcher relied on reading and interpreting the curve extracted according to the phases of walking technique, where both Jcquelin Perry & Judith M. Burnfield. (13), stat that walking movement is divided into two basic phases (stand, swing). and these phases have been divided into several phases as shown in the fig.12, According to the walking curve of the left foot value platform, an increase in the curve of the reaction force is shown at the first phase of the walk, which is called the initial contact. And since the player's body is behind the foot, the amount of reaction force value is small, and this is what the current platform shows. Then the player begins to move on the same foot of the stand to the second phase, which is the phase of loading response. At this point, the curve begins to rise due to the increased loading on the platform . But the center of gravity of the general body behind the foot of the anchor, with a double support foot, Then the ground reaction force curve continues to rise, reaching its highest peak in the third phase, which is the middle of the support, due to the orthogonality of the body's center of gravity on the support foot and the platform. Then the curve begins to landing in the fourth and fifth phase, which is the end phase of the terminal stance and preparing swing, Due to the change in body position from perpendicular to the tendency in front of the support foot, and in terms of the time taken for the support phase, it reached 0.7 seconds for both platform No. 1 and No. 2, which is proportional to the total time of the walking step and the linear velocity according to the walking technique, At the initial contact left foot, the right foot starts to begin and the right foot curve appears, so the foot curve appears to be overlapping at time 0.65 (Sec), and at that moment in time the feet become in a double pivot stage again, At the initial swing left foot, the right foot starts to initial contact , and the right foot curve appears, so the foot curve appears to be overlapping at time .0.65 (Sec), and at that moment in time the feet become in a double support phase again, Figure.11-B shows a wavy curve for platform No. (1) and (2) for the running technique. It is noticeable that the curve up and landing during a short period of time compared to the time of the walking curve, where the average running time reached .0.17 (sec) thanks to the linear acceleration of the player.

Fig.11-B. shows a wavy curve for platform No. 1 and No. 2 for running technique. It is noted that the curve goes up and down during a short period of time compared to the time of the walking curve, where the average running time reached .0.17. (sec) thanks to liner acceleration of the player. The running is divided into the support and the flying phases; as a result there is no overlap between the values of the right foot reaction force curve and the left foot reaction force curve, as is the case in the walking technique, and the reason is that there is no double support here for the two foot according to the running technique And the end of platform curve No. (2) began to appear after the platform curve No. (1) values in .0.07(sec).

The previous explanation for the curves of walking and running shows that the researcher has been able to develop a force platform, in terms of the ability to show the quantitative differences in the amounts of ground reaction force between the different performances in proportion to the nature of the motor performance technique in walking and running.

Second: The ground reaction force curve resulting from the test of both the vertical jump and the standing with firmness of the force platform (1), (2) for the right and left foot Fig. 13-A. B.





13-fig.B

fig.13 – A

Fig.13. the wave curve of the stand and the vertical jump of platform No. (1) for the left foot and platform No. (2) for the right foot.

Where the platform curve No. (1), (2) shows.13. A-B. the vertical jump phases of stability, which are three basic stand, firstly the standing standing still, where the athlete must stand upright, this phase two main purposes. First is to define the threshold for the beginning of the movement [12,8,7, 6, 3], by identifying the player weight which is (50 kg) distributed on platform No. 1, (2). Fig. 13 .B. shows the researcher stability to accurately calibrate the player weight during the time period starting from (0.0s) to (0.8) second to subtract the average amount of weight force from the amount of momentum and flight to Calculate the amount of push effort and this is shown by the platform.

Third: the propulsion phase. This phase begins when the athlete's velocity is equal to zero at the lowest level of the curve and the maximum contraction of the knee joint, then it rises by the force of reaction as a counter reaction to the highest peak of the curve and the maximum extension of the knee joint ,in which the header velocity of the body is equal to zero and becomes under the influence of the gravitational force only and according to the curve in the fig.13.B. it starts at(3.0sec) to (78.0sec).

The previous presentation shows that the researcher managed to design and manufacture a platform to measure the ground reaction force, which is characterized by (metal elasticity, small size and thickness, the ability to measure the force of each foot separately ,and the ability to take 600 Hz per second), and which have undergone an accurate calibration by the typical non-linear relationship.

Conclusions: -

- The researcher was able to develop and manufacture a platform with a metal elasticity to measure and analyze the dynamic force as a prototype .
- Calibration accuracy was validated by the typical relationship between the force and resistance of the FSR sensor, which is a non-linear relationship, and based on this the mean square root of the error was used, and finding the factors that achieve the lowest possible error, and that relationship was represented in a mathematical formulation as follows.

(3)

$$F = \left(\frac{186.7440}{R}\right)^{1.06887} \quad \textbf{Right leg sensor}$$

(4)

$$F = \left(\frac{797.24}{R}\right)^{1.12676} \quad \textbf{Left leg sensor}$$

- The researcher was able, through the proposed engineering design and through multiple applications at different times, to measure and analysis the dynamic force of standing, walking, running, vertical jumping. The designed device presented differences according to the nature of the technique and satisfactory results.
- In the light of the available capabilities, the researcher was able to manufacture a prototype at a low cost compared to the international prices for force platforms.

Recommendations:

- The expansion in the use of the prototype designed, by the Laboratory of Biomechanics, which was developed on the basis of sound science and engineering, which provides us with an assessment of the analysis of dynamic force immediately.
- Continuing to transfer industrial technology through development and manufacture, as it is the only way to learn and unveil the truth about the mechanics of the work of these important scientific devices in the field of specialization.
- A local company adopted this idea in terms of manufacturing as a final product intended for marketing and sale.

المراجع :-

أولاً المراجع العربية:

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