Building a Smartphone application to pair inertial sensors (Notch) for mechanical motion analysis

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Abstract:

The current study aims to design a software for mechanical motion analysis using smart phones with the possibility of coupling the proposed software for motion analysis with inertia units [Notch motion capture unit],which uses wireless communication and aims for tracking and monitoring the movement in three-dimensional space, whether inside closed spaces or in open spaces without being restricted to a specific place ,With the possibility of sending real time values and issuing an instant report,The researcher came up with the design of the proposed program for smart phones and was able to pair it with Inertia measurement units “IMUs”. The accuracy of the proposed software calibration was also verified, through the synchronization practical application with the [Simi motion system].The researcher reached a correlation coefficient from medium to very strong. The lowest correlation coefficient was (0.59) in the vertical distance. which is medium, and (0.99) in the horizontal distance (0.98) in the angle . which is very strong. The current study also showed the ability of the system to track any movement in the space at fractions of a second with an interval (0.03 s).The value of the differences in measuring the max ”IMUs” m velocity of the straight punch between the two systems was limited to a min”IMUs” m (0.05 m/s) and a St.dv of (0.04 ±), a max ”IMUs” m of (0.19 m/s), and a St.dv of (0.13 ±).

Introduction and research problem:

Sports movement is a universal language, with its vocabulary, syllables, sentences and common rules .It also has its own moral codes, charters, and laws, and there is innovation and creativity that amazed audiences all over the world .The contemplator on the skill levels of performance will find beyond any doubt that science has made a great leap and is still steadily leaping forward to achieve the greatest progress .The ambition of its scientists plays a key role in relying on modern technology to be the starting point for progress.

Where modern technology has invaded different areas of life, it was necessary to reach the sports field to raise the levels and help the player and coach to highlight the best of their natural human capabilities .By improving and developing methods of training and arbitration as well as the manufacture of training aids .[2:12)

Steve Hake (2009) indicates that there is a noticeable and tangible development in the level of performance that was reflected in the level of achievement by entering sports engineering and entering digital technology and technical devices in motion analysis and evaluating the

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level of technique and its components with scheduling information for each player, regardless of the number of attempts. [23:2]

The sports equipment which came out to the world according to the advanced scientific and technical concepts, are the ones that express the level of technology of the modern era .Where there is now a huge number of various innovations and inventions that serve the different sports fields .Which are due to the real reasons for improving and facilitating the training process through the ease of obtaining .Recording and analyzing information, It is also very easy to realize the importance of sports technology through a comprehensive and quick look at sports, Olympic and world achievements .As it calls for astonishment and admiration, all thanks to the tremendous technological progress that has crossed the limits of humanity to achieve the best results and reduce the chances of infection.

Research problem :

Motion capture or tracking is a general term that describes the reconstruction of actual motion in three-dimensional space. Human motion is the primary goal of motion tracking due to its anatomical complexity and organic properties. [22]

In fact, there are many types of motion capture or tracking systems. And these types are numerous for many purposes. Some of them are looking for the accuracy of the calculated values, some of them are looking for economy in cost, others are looking for a reduction in complex tools and equipment, and some are looking for non-compliance with a specific place as Study No. (9 , 10, 11, 12).This resulted in a multiplicity of hardware systems, as well as the software used for each of the motion analysis systems. All of the above falls under two systems. Which are the optical system and the non-optical system, optical systems are systems that use data that has been monitored by cameras and present that data in a three-dimensional image (X.Y.Z). And that is between two or more imaging cameras that have been previously calibrated. And the data of the points is collected using a reflector placed on the joints or centers of math of the parts. However, these systems, despite the accuracy of their results, have several drawbacks, including: -

The multiplicity of equipment for optical systems in terms of the number of cameras used to monitor and track movement, so that the three spatial levels are covered [X .Y. Z],the number of cameras used in filming shall not be less than three cameras of the same type, provided that they are distributed in a way that ensures that all the observed points can be seen together. Where the average number of cameras ranges from 2 - 48 cameras in some systems. There are other optical systems consisting of 300 cameras, such as the passive markers system . These systems also require the presence of a lighting system and its own calibration system, where camera calibration in optical systems is a mathematical and engineering problem in the field of computer vision. So researchers use two- or three-dimensional geometric models. Therefore, these systems are lamented because they are high cost and complex to install and use. And researchers bear a high financial cost in return for using these systems, also. Points that are hidden from the camera and placed on joints or centers of math of parts cannot be seen by optical systems, which are limited in the number of cameras, and therefore data is lost at those moments. In addition to the player's adherence to the calibration area and the place of filming, where the capture must be inside the lab and in areas not exceeding 2 x 2 m or 3 x 2 m in dimensions.

After completing the imaging in light of the previous equipment, the analysis process comes using software specific to each system, after completing the imaging in light of the previous equipment, the analysis process comes using software specific to each system, and it is a tedious process that requires the person in charge to follow it, moment by moment, even if the analysis is automatic. Because there are anatomical points that are lost either because of their disappearance or poor vision and lack of image purity due to the weak camera frequency or inappropriate lighting. And then the person in charge of the analysis begins to make a master file that contains building a model for the analysis process with the introduction of his calibration unit (graphic scale) which It requires special specifications. Where a picture is capture of him in the field of performance and then it is called within the program when preparing the analysis model. for the body) frame by frame until the end of the film. [1:34]

And the research problem that the researcher aim to solve is to solve the problems of the aforementioned optical systems, while trying to overcome the difficult technical challenge, which is the analysis of human movement in its natural state, without being restricted to a specific place or time or complex installation equipment and use. This is to make it easier for both the player and coach to do the assessment process by tracking and analyzing movement directly ,with the possibility of obtaining instant feedback. And advanced movement technology to monitor movement allows mobile devices to see accurately, it understands, and measures human movement. All thanks to emerging technologies and continuous research in computer vision, such as the study [13,14,15,16] .[26, 27]. Which leads to the rapid development of non-optical vision systems to monitor movement, which is the second type of motion capture systems. Including the system of inertial sensors.

Where the inertial motion monitoring system relies on the technology of miniature sensors and mechanical models, and that technology relies on the wireless feature to send motion data to a computer (smart phones).Where data is recorded and motion displayed in 3D stereoscopic images, most inertial sensors “IMUs”. contain (gyroscope, magnetometer, accelerometer,) to measure rotational rates that are translated in the form of a skeleton like reflector-based optical systems. This system is characterized by 6 degrees of freedom of movement for the human body with the possibility of displaying the results during real time. And one of its advantages is to monitor and track movement in different environments, whether in narrow spaces or large areas at night or during the day, indoors or outdoors.

The researcher believes that this makes it easier for users, who are the coach and player in the sports field, to monitor and track movement in its natural state and in the open air without being restricted to a specific place or time. With the possibility of generalizing the use of mobile devices and innovative application as an economic alternative to sports movement analysis laboratories for clubs, youth centers and workers in the field sports . And then the possibility of carrying out the motion analysis of the skill with direct and objective evaluation.

Therefore, the researcher in the current study suggests building an application for smart phones based on the android operating system, with pairing or connection with inertia sensors (Notch). With the aim of making the analysis process for those who analyze the sport skill easier in terms of use and not being restricted to a specific place. This application is now running on android and is only built into (PC). The researcher will work in the designed application to issue commands from users and send them to the central unit that performs the motion analysis (Notch), with receiving the immediate report on the analysis of the sports movement during real time.

Search aim:-

Building a smart phone application to pair inertial sensors (Notch) for real-time kinematic analysis.

Research questions:-

- What is the optimal design of application interface for the proposed mechanical motion analysis for smart phones and how to associate the proposed application with inertial units [“Notch”]?
- Is it possible to capture a point in the three-dimensional space with the possibility of the proposed application to send and receive orders and analysis data during real time?
- How to validate the accuracy of calibration of the proposed application for smart phones pairing with inertial sensors “Notch”?
- Are there significant differences between the proposed unit of motion analysis for smart phones and the visual vision system [SIMI motion] in the values of instantaneous velocity of the head straight punch?

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 researcher used the experimental method, with the aim of conducting practical applications of the proposed application for smart phones, to ensure the effectiveness of the application and the ability to pair the units [“Notch”].

The research sample:-

The research sample was chosen by the intentional method, which was represented by (5) boxer. To implement the practical applications of the proposed motion analysis software using "IMUs" , to calculate the quantitative values of some kinematic variables (time, distance, velocity, angle).

Equipment and tools used in research:-


fig[1]

- 6 inertial [Notch units].
- An android smart phone.
- 2 cameras [Basler] with a frequency of 120 frames / second.
- Simi motion analysis system.
- Anatomical point reflector.
- Lab view software.


fig [2]

Suggested movement analysis unit parts and components "IMUs"

(1^{nd}): the tracking units [Notch]:-

Notch: A wearable motion capture system that tracks movement through smart phone apps. One of the world's most advanced motion sensors that can be worn through lightweight belts, these units have everything a specialist needs to capture the minute details of body movement, allowing review and analysis of how real movement is on your smart phone in an interactive "IMUs" lation environment.


Fig [3]

(2^{nd}) IMUS":-

"IMUS" s are sensors that are an electronic device for measuring and giving reports on the rate of angles and force of objects and also for measuring the position in space in a three-dimensional space. It is a supplement to the Global Positioning System (GPS). In addition, they are found in a variety of consumer electronics devices that contain motion and positioning sensors (such as smart phones). The type of "IMUs" used is characterized by 6 degrees of freedom, and "IMUs" consists of (accelerometer group - gyroscope - magnetometer) [25] [24].

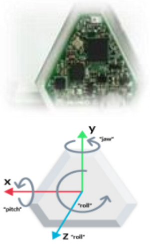
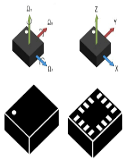


Fig [4]

(3^{nd}): accelerometer:-

Accelerometers are used to sense static (gravity) and dynamic (start/ sudden stop) acceleration. The tilt sensing is one of the most widely used applications of accelerometers. And smartphones have an accelerometer, which lets it know if what's being held is in portrait or landscape mode. The accelerometer can also be used to sense motion. For example, the accelerometer can be used to sense the forward and backward strokes of a tennis racket, or the rotation of a bowling ball. [26]


Fig[5]

(4nd): (A gyroscope):-

A gyroscope measures angular velocity, how fast something is rotating about an axis. As it monitors the direction of a moving object, the accelerometer may not give enough information to know exactly how to steer it. The gyroscopes are also not affected by gravity, so they are complementary to each other. Angular velocity is represented in units of rotation per minute (RPM), or degrees per second (°/s). The three axes of rotation are denoted as [X.Y.Z]. [26]

Fig [6]

(5nd): (Unity 3d):-

Unity is a game development platform that is used to build high quality 2D or 3D games and can be used on mobile or desktop devices.

Fig [7]

(6nd): smartphone:-

It is a smart mobile device running on Android operating system with min"IMUs" m operating requirements of the application designed, equipped with Intel Atom Dual Core processor with 4 GB of RAM and 64 GB of internal storage. And a 5000 mAh lithium battery for greater operating time. And a large screen measuring 5.7 inches, which makes it suitable for people who want a large screen size without the need to buy a tablet computer.

Fig [8]

(7nd): Operation Theory:-

"IMUs" are sensors installed on the human body designed to measure 3D directions. It is also used by the 6 "IMUs" analysis unit, which is placed on the upper end of the body, where the "IMUs" sends data to the mobile device through the FTDI board that will convert the "IMUs" sensor into a protocol compatible with the mobile device wirelessly and read the signals on (ROLL, PITCH, YAW0) ,from the device sensor and send this data to the mono develop C# editor which will pass this data through mathematical equations and commands that will allow the 3D unit to refer to a 3D human skeleton. The module will 3D and send this data to Lab view software to calculate the average angle and calculate the angular acceleration in a fraction of a second, and then send the results of the calculated angles to an Excel sheet after stopping the lab view application immediately.

Steps for placing the sensors on the rigid body:-

The researcher relied on clauser's model in determining the centers of gravity of the parts through the following steps: -

* Measuring the true length of the arm extensions (hand - forearm - upper arm - trunk)

* Determining the position of the center of mass of the connections and recording them in table (1) through the following equation: -

Position of the center of mass = percentage radius mass* mass length/100.

* In light of the value extracted from the equation, the position of the center

of mass, measured from the upper edge of the mass, as shown in table (1), figure (9)

* The sensors are placed on the centers of mass as shown in figure (17).

Table [1]

N	Mass name	Masslength	Radius ratios	Ce.of. mass
1	Hand	20 [cm]	18%	3.6
2	Fore arm	30 [cm]	39%	11.7
3	Upper arm	26 [cm]	51.3%	13.338

Extraction of centers of mass

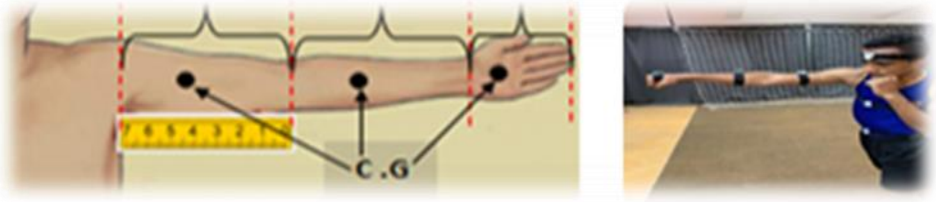


Fig [17]

Measuring the length of the mass and determining the centers of mass

Statistical analysis:

Mean - standard deviation - standard error - Pearson correlation - Linear regression - Bland . Altman diagram .

Presentation and discussion of the search results:

First : What is the optimal design of application interface for the proposed mechanical motion analysis for smart phones and how to associate the proposed application with inertial units [“Notch”]?

The researcher designed the application with all its interface in the arabic language, and the design relied on software libraries specialized in tracking and monitoring movements belonging to the wear notch company that specializes in products for sports movement such as tracking units. Which is the company that produces the tracking units that were used in the current research, and the final output was about one executable file in the [APK] format, which is the basic format approved for running applications on the android smart phone operating system.

First: the main interface of the application:

Application opening interface:

Where the application starts by touching the program icon that appears after downloading and placing it on the smart phone, then this opening interface appears, which expresses the program’s logo and name, and if any problems appear during the download, the program will stop at this interface with the appearance of a message shown there is an error in the download. fig (10)

fig [10]

The main interface of the application

fig [11]

In it, three places appear for different inputs. The first place shows the list of the attached devices represented by the tracking “IMUs” that are connected through the network. The second place shows the name of the network that is currently connected. Then the third place: It shows the license key through which communication with the server of the tracking “IMUs” is shown. fig (11)

Device management interface through the application:-

It is the interface through which the tracking units are managed by linking, decoding or deleting them, as follows:

* New device Pairing button: From this button, the user can add a new “IMUs” tracking unit by connecting it to the bluetooth network.

fig [12]

* Peripheral devices synchronization button: From this button, the user synchronizes all the information of the units associated with it, which are represented in their position, function and the color of their lighting. Where each unit has a different color.
* Delete all devices button: With it we do the complete deletion of all links between the units and the application.
* Accessory close button: Through it, we close the tracking units “IMUs” so that the electricity supply to the unit is cut off, which leads to it stopping working and thus cutting the network between the unit and the motion analysis software designed by the researcher.
* Extension scan button: Through it, the positioning information and tracking information between the proposed software and all “IMUs” are erased without losing or disconnecting between them. (Fig. 12)

Hardware calibration interface:

Calibration is the process of freeing the tracer “IMUs” from any stored information from previous operations, and this process is performed to ensure that the units are ready for a new analysis process. Here is an explanation of how these buttons work:

fig [13]

* A button without preliminary selection: Through it we can skip the calibration process
* Calibration setup button: In it we put the settings for the calibration process.
* Accessory calibration button: This button starts the calibration process of the units.
* Calibration information button: It shows some information from the calibration process that has been completed. (Fig. 13)

Stability test interface:

fig [14]

It is concerned with making a test of the “IMUs” associated with the proposed application (the proposed software) and collecting information about the locations of each unit on the body, as well as linking this information to the three-dimensional structure that depicts the movement, moment by moment. It is correct about the spatial coordinates of the points.The following is an explanation of the buttons for this part:

* Attachment number button the button that specifies the number of units on which the stability test is performed.

* The stability test setup button which clears the way for test work by signaling all “IMUs” to get ready.

* The stability test start button is the main button that starts the test and collects the information needed to start capture. fig (14).

capture start interface:

It is the main interface of the program through which the imaging, recording and uploading to the server of the motion tracking units manufacturer “Notch” is done, and the imaging is done through a few simple steps, and the following are the explanation of these steps.

* Real-time button: by means of which the real time is activated and the feature of selecting a specific time is made.

* Number of accessories button: It is the button that determines the number of “IMUs” that are installed on the player's body and then start the process of capture and uploading.

* The actual capture setup button: Through which the units are prepared and ensure that the units are installed on the player’s body in a proper manner, by giving a signal to all units to prepare.

* Start capture button: It is the main button that starts tracking the movement and connects it directly to the three-dimensional object that represents the player's movement on the application and then uploads it to the server for safekeeping in the future.

Fig[15]

* Actual capture stop button: This button is concerned with stopping the process of recording the movement of the units installed on the athlete's body and starting the process of uploading the part that was captured or recorded to the aforementioned server to save it for future use.

*”IMUs” late capture button From this button we can review the recording that was uploaded to the server and review the virtual work with the original movement.

* Show examples button which lists some examples previously issued by the tracking unit manufacturer. fig (15)

Second: Steps to operate and use the device:

Below, the researcher will present the setup process, and how to pair the tracking units “Notch” with smart phones, through the application that was designed for the purpose of this research. And then start capturing the player's movements using the designed application.

- **Setting the tracking units:**

Each tracking unit has an internal button that can perform multiple functions. This button turns the units on and off, and also starts recording or used with the programming update feature. The way it works is that you press a light pressure on the front of the unit - or put it between two fingers and then press it with both fingers until you hear a slight click, then you will notice a white flash from the built-in lamp with the IMUs. It is very important not to use excessive force when pressing the unit button. If the unit does not respond to pressure, place it on the charger and wait for it to charge.

- **Associate the “IMUs” with the application (suggested software)**

The user must pair and calibrate their units before use, each tracking unit needs to be paired to the smart phone before use. The pairing of units is done once per application. The pairing is done in an easy way, which is as follows:

1. Run a single tracking unit.
2. Open the application and press the "Pair new device" button.
3. Wait for a notification from the app that the pairing is complete.
4. Stop the operation of the paired IMUs.
5. Repeat steps 1-4 for all existing IMUs. fig (16)

Fig [16]

Secondly: Is it possible to capture a point in the three-dimensional space with the possibility of the proposed application to send and receive orders and analysis data during real time?

The researcher was able to answer the second question through the use of inertia sensors [Notch] that work by detecting the rate of acceleration in a three-dimensional space. And also detecting the rotational changes that occur at one point on each of (yaw, pitch, roll).(5 : 1)

Also used were sensors located inside the notch- “IMUs” unit, which are gyroscopes and magnetometers, all of which are used to calibrate against any deviation that may occur in the measured values. And the inertial system contains the “IMUs” , which has angular acceleration and linear for any change in the position of the observed points. To adjust and adjust the horizontal angles in the direction of yaw.

As for how to measure angular acceleration in a space, there is at least one sensor for each of the three axes. Which is pitch (up - down), and its standard power is between (-180°... 180°), yaw (right - left) and its standard capacity is between (-180°…180°), roll (counterclockwise) and its standard capacity is between (-90°…90°). (5:1)

The inertial sensors “IMUs” used in the research are one that combines acceleration and gyroscope to display complete information about acceleration and the ability to determine the position and direction of a point in a space, velocity and other variables.

In light of the foregoing, the researcher was able to install these sensors on the rigid bodies of the human body (rigid bodies), which are (hand - forearm –upper arm - trunk) (Fig 17).Where these sensors are connected to a central control unit using microcontrollers. These sensors were attached wireless to the central unit to communicate with the smart phone unit (station).Through which movement was monitored and various transactions were used. And for the accuracy of tracking the movement, high-precision sensors were used so that any movement could be tracked in milliseconds, as well as a high-velocity central control unit was used to send commands from users and receive data from all sensors at each operating cycle, and send it to the smart phone unit at high velocitys through which to track the dynamics of movement And monitor all its kinematic variables during real time.

Fig [17]

Third: How to validate the accuracy of calibration of the proposed application for smart phones pairing with inertial sensors “Notch”?

The motion analysis unit calibration is divided into two parts. The first relates to the inertia units used in the research [notch motion capture], and the second is to conduct laboratory experiments between both the non-visual vision system, which is the mechanical motion analysis system proposed by the researcher, which consists of (inertia units associated with the smart phone software) With the optical vision system, which is a (Simi motion unit) system. In order to verify the accuracy of the values of the basic physical quantities (time - distance) between the two systems.

First: calibration of inertia units

Calibration is the process of adjusting units to take into account the environmental factors in which the analysis takes place. It is a simple process, and the opt ”IMUs” m performance of these units is that the units must be calibrated at the beginning of each motor skill recording session. The units must also be re-calibrated if moving from one place to another with significant differences in the surrounding areas. For example, it would be better to re-calibrate the units if moving from an internal site to an external site, and the calibration is done as follows:

- Put all units in their appropriate slots in their own box and close the box cover. fig (18).
- Click on the “accessories calibration” button in the designed application.
- Rotate the unit box following the instructions that appear on the screen in the application.

Fig [18]

stability test:

The stability test is done immediately before registration, which is the process of linking the application to the zero point from which it will start moving, and the stability test process is as follows:

- Click on “stability test” in the designed application.
- Stand straight, keeping the legs at shoulder width and directing all units forward along the body.
- When the application finishes recording the starting places, the application sends you a notification that the stability analysis test has been completed.
- It is very important to ensure a successful stability test, make sure that your arms and legs are next to the body, straight and facing forward. and Fig[19] shows the standing body stationary.

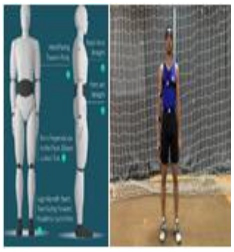


Fig [19]

Validation and accuracy of 3D motion analysis systems is a previously studied topic. Several studies have resulted from this subject, all of which aim to verify the accuracy of calibration of imaging systems, such as Study No. (6, 7,8).Where those studies in calibrating imaging systems relied on measuring distance and angle error as a quality factor to judge the accuracy of calibration. And other studies relied on measurement of displacement and horizontal and vertical velocity as study No. (19). So the researcher will depend on measuring both distance and angle as two basic variables to verify the accuracy of the calibration of the proposed system, which is a unit of mechanical motion analysis based on building motion analysis software for smart phones associated with inertia sensors.

The system was calibrated by comparing the results of the optical vision system based on the cameras, which is the Simi motion unit in synchronization with the mechanical motion analysis unit based on “IMUs” notch motion capture coupled with the motion analysis software for the smart phone and at a frequency of 40 images / s during athletic walking, and in the light of previous studies. Which was aimed at validation the accuracy of calibration of imaging systems as Study No. [6, 7,8].Where it relied in calibrating imaging systems on measuring distance and angle error as a quality factor to judge the accuracy of calibration. So the researcher will depend on measuring both distance and angle as two basic variables to validated the accuracy of the proposed system calibration, “Notch” sensors were placed on the centers of mass connections [hand, forearm, upper arm] Fig [9, 17].And a reflector [marker] was placed over each sensor and every point was monitored in the three directions [XYZ] for the optical vision system and the invisible vision system “IMUs” paired with the smart phone.

And it must be taken into account that each unit of inertia placed on the centers of masses of the body parts reads its coordinates according to its position in the space where the position of the point is its reference. Where before the start of the movement the reading of the coordinates of each point separately is [0 x.0 y .0 z].So to know the height of each point from the ground, realistic measurements must be taken to know the real height of the point from the ground.

In terms of the statistical analyzes used to perform calibration and verify the validity of the values extracted from the proposed system, the research relied on what was followed for previous studies such as Study No. [19].Where linear regression, Pearson correlation coefficient for quantitative measurements with 95% confidence intervals (CI) and standard error of estimation were used. (SEE). Pearson's correlation coefficient was interpreted as follows: 0.9 to 1.0 = very strong correlation, 0.70 to 0.89 = strong correlation, 0.40 to 0.69 = medium correlation, <0.40 = weak to little correlation and table (2) shows this.

Table (2)

Pearson correlation coefficient and standard error of measurement between two systems of motion analysis unit associated "Notch" and system [Simi motion] in the variable distance and angle

frame	Time [s]	Non optical ["Notch"]			Optical [Simi motion]			Differ Perc (%)			Std. Error			Correlation .person(95%)		
		Chest bottom (distance/M)		Angle (degree)	Chest bottom (distance/M)		Angle (degree)	Chest bottom (distance/M)		Angle (degree)	Chest bottom (distance/M)		Angle (degree)	Chest bottom (distance/M)		Angle (degree)
		X	Y	R.knee	X	Y	R.knee	X	Y	R.knee	X	Y	R.knee	X	Y	R.knee
1	0.025	0.004	1.402	178.28°	0.04	1.411	179.2	0.036	0.009	0.92	0.018	0.005	0.460	***0.99***	***0.59***	***0.98***
15	0.375	0.004	1.408	169.63°	0.049	1.426	168.52	0.045	0.018	-1.11	0.023	0.009	0.555			
31	0.775	0.053	1.412	141.43°	0.089	1.431	143.53	0.036	0.019	2.096	0.018	0.010	1.050			
47	1.175	0.25	1.389	178.52°	0.46	1.376	177.24	0.21	-0.013	-1.285	0.105	0.007	0.640			
63	1.575	0.527	1.399	176.69	0.751	1.41	177.24	0.224	0.011	0.544	0.112	0.005	0.275			
79	1.975	0.798	1.393	154.18	0.645	1.378	151.33	-0.153	-0.015	-2.855	0.077	0.008	1.425			
95	2.375	1.097	1.409	135.11	1.064	1.428	137.25	-0.033	0.019	2.14	0.017	0.009	1.070			
111	2.775	1.439	1.38	171.68	1.632	1.335	173.87	0.193	-0.045	2.19	0.096	0.023	1.095			
127	3.175	1.743	1.408	177.14	1.809	1.431	169.36	0.066	0.023	-7.78	0.033	0.012	1.110			
143	3.575	2.027	1.397	119.07	2.325	1.375	123.54	0.298	-0.022	4.47	0.149	0.011	2.235			
159	3.975	2.312	1.395	177.23	2.512	1.374	178.96	0.2	-0.021	1.73	0.100	0.011	0.865			
175	4.375	2.637	1.399	175.95	2.795	1.431	176.47	0.158	0.032	0.52	0.079	0.016	0.260			
191	4.775	2.909	1.395	155.75	3.089	1.23	153.82	0.18	-0.165	-1.93	0.090	0.083	0.965			
207	5.175	3.159	1.405	166.58	3.325	1.43	168.22	0.166	0.025	1.64	0.083	0.013	0.820			
243	6.07	3.503	1.373	174.39	3.468	1.355	175.87	-0.035	-0.018	1.48	0.018	0.009	0.740			

Table (2) shows the values of the Pearson correlation coefficient with a 95% confidence interval, as well as the values of the standard error of measurement for both the horizontal displacement, the vertical displacement and the angle between the proposed application and paired with the "Notch" of smart phones and visual vision system [Simi motion] while walking trunk.

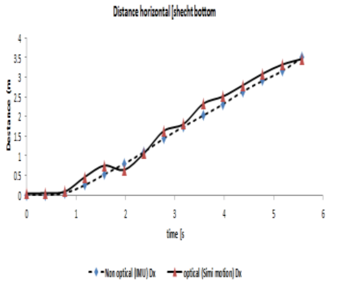
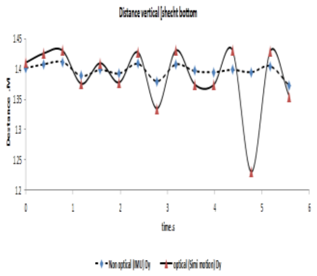
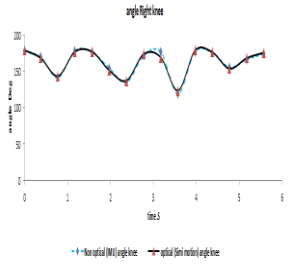


Fig (20) horizontal distances

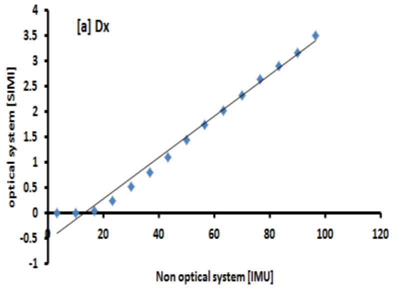


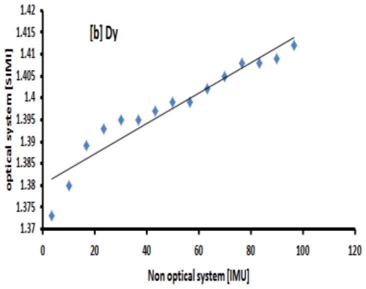
Fig(21) Vertical distances



Fig(22) Right knee angle

Figure (20,21,22) shows the geometric curves that indicate the results of the comparison between the proposed software application and the associated "Notch" for smart phones and a system, for both horizontal and vertical distances and the angle.





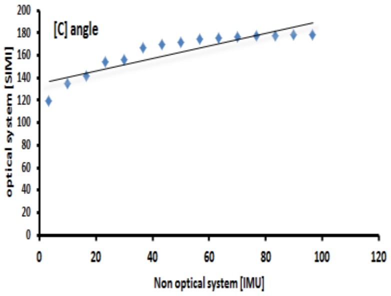


Fig (23, 24,25) shows the linear regression of the horizontal and vertical distances and the angle between the application of the proposed software using "IMUs" for smart phones and the [Simi motion] system.

The need to assess and monitor the physical condition and skill performance of athletes has led professional athletes to use equipment that may not be available in some sporting contexts. Therefore, the use of mobile applications for these purposes has gained interest among the sports and scientific communities. However, trainers need to be confident that these apps measure what they are supposed to measure, and that their measurements are consistent and repeatable over time. (21:17)

In order to verify the reliability of the system, the researcher calibrated the motion analysis software associated with the smart phones "IMUs" and compared its results to another pre-calibrated system that has a global reputation. Which is the (Simi motion) system, the results of that comparison came in table (2) and Fig (20,21). , 22), in some kinematic variables of trying to walk (distance, angle). The results of the current study showed the values of Pearson's correlation coefficients, which ranged from medium to very strong, the lowest correlation coefficient was (0.59) in the vertical distance [b] Dyit is medium, (0.99) in the horizontal distance [a], Dx (0.98) in the angular change [c] angle, and it is very strong.

These results are consistent with previous studies that analyzed the validity and reliability of various applications based on video analysis to measure distance and angle, such as Study No. (17, 18), as well as studies that were based on the comparison between applications based on video analysis and applications based on smart phone software, such as Study No. (19) (21), Pearson's correlation coefficient values ranged from (0.729 to 0946) for the (my lift) application in previous studies that depended on smart phones to monitor and track movement, and (0.54 to 0.93) for the smart phone accelerometer application. What is between the current study and other previous studies of video-based applications used to measure some mechanical variables, is that the current study is one of the first to use an application with computer vision algorithms on smartphones paired with inertial "IMUs" with the aim of non-invasively tracking the trajectory of motion. Non optical system. The displacement and angle patterns throughout previous studies have shown moderate and strong to very strong cross-correlation coefficients. Correlation between (0.862–0.999).

Therefore, the researcher believes that the degrees of the correlation coefficient indicate that there is reliability in the motion analysis software for smart phones associated with "IMUs". Where the accuracy of calibration of the proposed software was verified, and the results of the current study showed small to small differences in the degrees of standard error of estimation for the data contained in the study. There are slight differences between them and between previous studies that used slow motion applications, where the standard error of measurement in the current study ranged between (0.005 to 2.23).And the standard error of measurement in previous studies ranged between (0.001 to 0.029).Due to the researcher indicated that previous research had used different exercises from the movement that the researcher applied to, or other criteria for statistical comparison, or kinematic variables and different methodological procedures.

Third: Are there statistically significant differences between the proposed unit of mechanical motion analysis for smart phones and the visual vision system [Simi motion] in the values of the instantaneous velocity of the straight punch to the head?

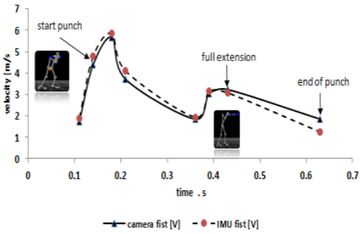
Table [3]

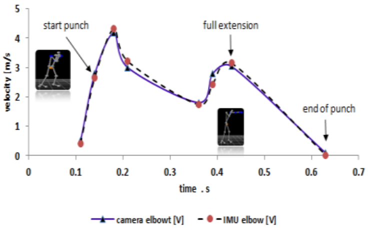
Correlation coefficient and standard deviation degree for calculating some linear kinematic variables of (straight punch) Between the proposed application for smart phones and paired units “Notch” and the [SIMI motion] system in a variable velocity

frame	Time	Optical [Simi motion]			Non optical “Notch”			Std. Dev			Correlation .person(95%)		
		velocity [m/s]			velocity [m/s]			velocity [m/s]			velocity [m/s]		
		Fist	elbow	shoulder	Fist	elbow	shoulder	Fist	elbow	shoulder	Fist	elbow	shoulder
		XY	XY	XY	XY	XY	XY	XY	XY	XY	XY	XY	XY
3	0.11	1.73	0.51	0.89	1.90	0.42	1.03	±0.12	±0.06	±0.10	0.98	0.99	0.95
4	0.14	4.38	2.78	1.47	4.78	2.65	1.55	±0.28	±0.09	±0.06			
5	0.18	5.67	4.17	1.65	5.86	4.31	1.70	±0.13	±0.10	±0.04			
6	0.21	3.71	3.00	1.32	4.10	3.21	1.41	±0.28	±0.15	±0.06			
10	0.36	1.85	1.81	0.60	1.94	1.74	0.83	±0.06	±0.05	±0.16			
11	0.39	3.04	2.79	0.81	3.16	2.42	0.72	±0.08	±0.26	±0.06			
12	0.43	3.23	3.04	1.09	3.08	3.15	0.84	±0.11	±0.08	±0.18			
18	0.63	1.85	0.09	0.21	1.25	0.02	0.12	±0.42	±0.05	±0.06			

Kinematics variables	Optical [Simi motion]	Non optical [“IMUS”]	Deference	percentage	Std. Dev
Max fist V m/s	5.67	5.86	0.19	% 3.2	±0.13
Max elbow V m/s	4.17	4.31	0.14	% 3.2	±0.10
Max shoulder V m/s	1.65	1.70	0.05	% 2.9	±0.04
Fist Duration (s)	0.64	0.64	0	% 0.0	±0.00

Table (3) shows the values of the Pearson correlation coefficient with a 95% confidence interval, as well as the standard deviation values of the instantaneous velocity variable for each of the fist, forearm, upper arm, and max ”IMUs” m velocity by comparing the proposed software and paired with the “Notch” for smart phones and the [Simi motion] system during the straight punch in head .





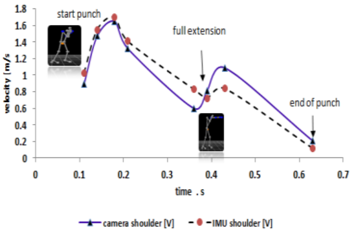


Fig (26,26,28) shows the geometric curves of the instantaneous velocity of the connections (the fist, forearm, upper arm) between the two proposed software systems associated with the “Notch” for smart phones and the [Simi motion] system.

The aim of this stage is to make a practical application to one of the sports, which is boxing, in which the motor performance is characterized by the motion velocity in the performance of punches fig (29). In order to verify the ability of the proposed system to issue commands and receive the results of the analysis while testing the accuracy of capturing the movement at small moments of time with an interval (0.03 s) between the image and the image immediately following it, table (3) ,fig (26,26,28) show the results of the comparison between the two systems (motion analysis software system coupled with ”IMUs” and (Simi motion) and the ability to measure the instantaneous velocity of the straight punch in the head at a confidence degree of 95 The values of Pearson's correlation coefficient ranged from strong to very strong between the two systems. Where the Pearson correlation coefficient for fist velocity was (0.95), forearm velocity (0.99) and upper arm velocity (0.95), and the standard deviation was limited to a min”IMUs” m (0.04±) and a max”IMUs” m. (0.42±).

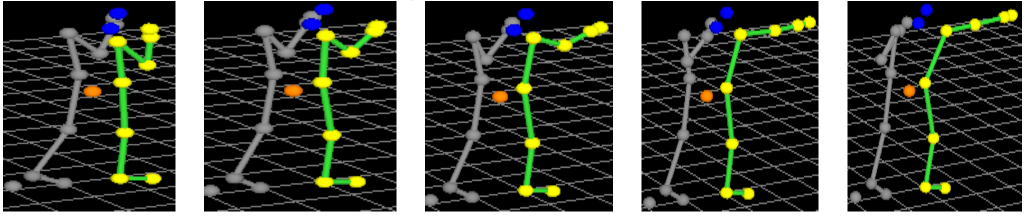


Fig (29)

And to confirm the ability of the proposed application to issue commands and receive the results of the analysis with capturing instantaneous measurements, the researcher measured the maximum velocity, which is at the moment when the arm is fully straightened. The maximum velocity of the fist reached (5.86 m) for the proposed system, (5.67 m/s) for the (Simi motion) system with a difference of (0.19 m) / s) with a percentage (3.2%) and a standard deviation (0.13 ±) and the max”IMUs” velocity of the forearm (4.31 m / s) for the proposed system was (4.17/s) for the (Simi motion) system with a difference of (0.14 m / s) and a percentage (3.2%), a standard deviation (0.10 ±) and the max”IMUs” m velocity of the upper arm (1.70 m/s) for the proposed system, (1.65 m/s) for the (Simi motion) system with a difference of (0.05 m/s) and a percentage (2.9%), and a deviation of Standard (0.04±).

The previous presentation of the results of the comparison between the proposed application and the internationally recognized system within the motion analysis laboratories, which is the (Simi motion) system, confirms the ability of the proposed application to pair with (Notch) units with capturing and tracking movement in a vacuum with the dynamic distribution of time with instant measurements. Where there is no difference in terms of time between the two systems, but it there are differences in measuring the instantaneous velocity, but they are slight differences between the two systems, and they are statistically acceptable.

Table (3)

The mean absolute difference of the Plan-Altman diagram with the minimum and maximum agreement with a 95% confidence interval between the proposed application combined with the [“Notch”] units and the [Simi motion] system

statistical analysis	V. fist [m/s]	V. forearm [m/s]	V. upper arm [m/s]
Mean absolute difference	0.076	-0.034	0.02
Lower LOA	-0.559	-0.395	-0.281
Upper LOA	0.711	0.328	0.321

95% confidence in each of the instantaneous velocity of the rigid body (the fist, forearm, upper arm) with the limits of the agreement for the lower limit and upper limit (LOA).

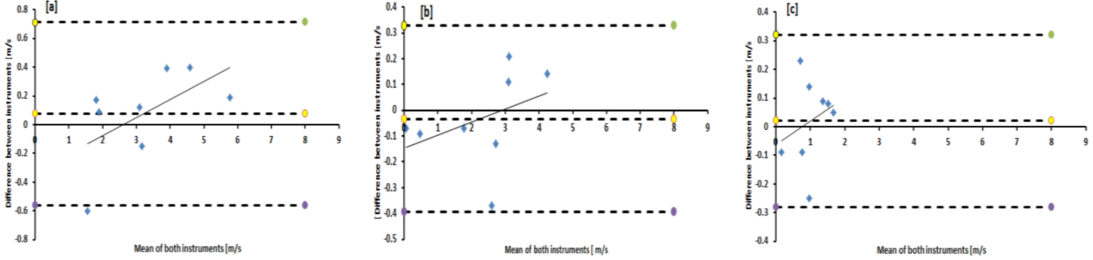


Fig [29, 30, 31] shows the Bland-Altman diagram of the differences between the two measurements and the limits of agreement (LOA) between the two systems for measuring the instantaneous velocity variable of the fist (a), forearm (b) upper arm (c). The solid diagonal line represents the regression line, and the dashed line represents In the middle of the figure is a Bland-Altman diagram and the upper and lower dashed lines represent the LOA.

Scientists Bland and Altman (1986) have indicated that any two methods that are designed to measure the same parameter (or characteristic) must have a good correlation between them, and the high correlation between any two methods in order to measure the same characteristic does not necessarily mean that there is a good agreement between these two methods. The reason for this high correlation is just a sign that the researcher has chosen a large-scale sample that caused this correlation.So Bland-Altman charts are widely used to assess the compatibility between two different devices of measurement techniques, and Bland-Altman charts allow identifying the systematic differences between the measurements [310 - 20]

Therefore, the researcher used the Bland-Altman chart of the differences between the two measurements to confirm the degree of agreement and reliability of the proposed motion analysis system for smartphones compared to the visual motion capture system (Simi motion), and in the light of table (3) and the graph of fig (29, 29, 31) showing the velocity values For each of (fist a), (forearm b), (upper arm c), it turns out that the vast majority of data points lie between the upper line and the lower line, where the absolute value indicates acceptance or rejection of the proposed system and rejects the proposed system if the absolute value exceeds (0.2 m/s) (6: 12)

According to the results contained in table (3) and the illustrated graphs (a, b, c), it is clear that the absolute value ranges from (0.034-m/s to 0.076 m/s), which are less than the specified value, and therefore these values give us a degree of reliability 95% of the proposed kinematic analysis software system for smartphones using inertial sensors “IMUs”.

Comparisons between the entire time-series data captured and derived from both systems also showed that they produce very similar spatiotemporal properties (in displacement and velocity-angle). Specifically, the cross-correlation coefficients between the data from both systems were moderate to very high for all data, indicating that the dynamic changes in the trajectory of the moving body are similar.

The results of the current study indicate that the data resulting from the application of the proposed motion analysis software for smart phones can be used to evaluate important temporal and spatial characteristics. for example, looking at the level of the boxers with the highest level and the most technically efficient we find differences in the max”IMUs” m velocity in favor of the technical competencies of the players, as coaches can use the application to monitor the velocity pattern before and after and training interventions.

Conclusions:-

Within the limits of the research objective and in light of the questions and the method used, the researcher was able to:

- The researcher was able to design and implement interface for the application of the proposed mechanical motion analysis for smart phones with the possibility of integrating communication and coupling with inertial units [“Notch”] in an optimal manner that is characterized by ease of dealing with those in charge of the analysis process..
- The current study showed that the application of the proposed motion analysis software for smart phones based on computer vision using (“Notch”) can track any movement in the space at small time moments with an interval (0.03 s), between the image and the image immediately following it, due to the use of a controller high-velocity centralization of sending commands from users at each operating cycle and receiving analysis data to the mobile phone at high velocitys (real time) by the proposed application.
- The proposed application for smart phones helped users not be restricted to a specific place where they could track and capture sports movement outdoors or indoors while not being bound by any other requirements.
- The results of the research show that the researcher was able to verify

the accuracy of the calibration of the proposed mechanical motion analysis unit for smart phones that is associated with inertial sensors “Notch” In the vertical distance it is medium, (0.99) in the horizontal distance (0.98) in the angular change and it is very strong. In a correct and reliable manner 95% compared to the optical motion capture system (Simi motion).

- The proposed application showed that the differences in the measurement of the maximum velocity of the straight punch between the two systems were limited to a minimum (0.05 m/s), a percentage (2.9%) and a standard deviation (0.04 ±), a maximum of (0.19 m/s), and a percentage (3.2%).), and a standard deviation of ±0.13.
- The results of the Bland-Altman diagram show the acceptance of the proposed application by the researcher, as the vast majority of data points for the velocity values for each of (the fist a), (the forearm b), and (the upper arm c) are located between the upper line and the lower line, where the absolute value refers to Acceptance or rejection of the proposed system The proposed system is rejected if the absolute value exceeds (0.2 m/s) and the values of the proposed system are limited between (0.034 m/s to 0.076 m/s), which are less than the specified value.

Recommendations:-

- The need to complement and develop the proposed system, as the researcher believes that techniques that allow accurate, rapid and unobtrusive measurement of human performance will affect the future of mathematical biomechanics using the latest computer vision and machine learning algorithms.
- This study should be added to the scientific literature, as it showed that a computer vision-based smart phone application can provide correct measurements of kinematic variables of sports movement.
- The necessity of using the application proposed by the researcher because it is of importance to athletes, sports scientists or coaches of different sports who want to analyze the kinetic performance pathways and diagnose situations during outdoor sports, with the ease of use of the application by those in charge of the kinetic analysis process. As well as indoor activities, and obtain an immediate report that shows us the level of performance.

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