A review on human motion capture techniques

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Abstract - **This paper will provide reader with overview of motion capture with simplicity. What is motion capture? history of motion capture, different technologies associated with motion capture and lastly applications, all these topics will be covered in this paper. There are various motion capture practices such as gesture capture, facial capture and body motion capture, but paper is mainly about the motion capture regarding body movement data capture in particular. Various types of motion capture system and their plus and minus points will be discussed along with difference in the system, followed by applications and conclusion.**

Keywords – ***Applications, classification, combinational systems, history, non-optical systems, optical systems.***

I. INTRODUCTION

The word motion capture has a self explanatory meaning to it. There are various fields where motion capture is used and there are variety of definition for motion capture. But the simplest explanation for motion capture is "motion capture involves measuring an object's position and orientation in physical space, then recording that information in a computer-usable form. Objects of interest include human and non-human bodies, facial expressions, camera or light positions, and other elements in a scene" [1].

In 1872, Eadweard Muybridge was trying to find out about the motion of a horse during a gallop, to find if all of horses legs are in air at certain point or not. For this he initially had a 12 camera array and was trying to take sequential shots of a horse while galloping. During 1878 to 1884 he perfected his method. Later on his method was used for other animals and humans too. The work he did with University of Pennsylvania was a substantial factor in development of biomechanics and mechanism of athletes [2].

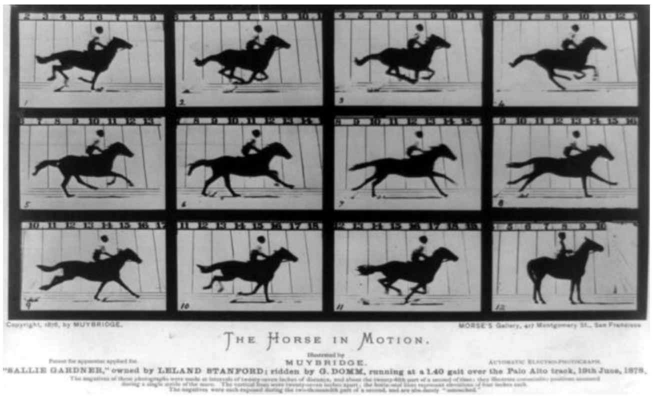

Fig. 1 Eadweard's horse in motion experiment

Like Muybridge, Etienne-Jules Marey was also studying human and animal motion by means of sequential photographs of subject in motion. Both of them were also developing devices that can record the movement graphically. But both studies were individually done [3]. In 1882 Marey made his own chronophotographic gun. It was capable of taking 12 consecutive frames in a second and all frames were recorded on one picture [4].

Fig. 2 Chronophotographic gun of Etienne-Jules Marey

In 1911, cartoonist Winsor McCay drew a character on multiple sheet of paper; each paper had slight change in the character movement. He then sampled them at constant rate which at the end created the illusion of motion using number of character drawings [5]. Then these ideas were used by cartoonist named Max Fleischer, which he transformed into rotoscope. Using rotoscope animators were able to trace the characters over photographs of performers. In 1980 'Preview' by Wavefront Technologies become first commercial package for computer animation. By this time character animation in 3-D was in use. This is how motion capture took off which was a graphical tool in biomechanics research in the beginning also expanded into other industries as technology progressed with time. And now it is used in major fields like medicine, sports, entertainment and many others [3].

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ISSN : 2454-9150 Vol-05, Issue-04, July 2019

II. CLASSIFICATION

There are few ways for classification of motion capture system. But the following shows the most simple and popular way to classify the motion capture systems.

A. Non optical systems

1) Mechanical systems-

Mechanical motion capture systems directly access body joint angles. The system is often referred to as exoskeleton motion capture systems, on basic of how the sensors are attached to the body. The exoskeleton suit is basically a mechanical skeleton which can do all the things a human body can do plus it should be body attachable [6]. Suits are rigid structures of jointed, straight metal or plastic rods linked together with sliders and potentiometers that articulate at the joints of the body [7]. In order to capture the motion each joint is connected to an angular encoder. By collecting the values of all the encoders; with respect to time and there positioning, we can recreate those movements. Sometimes an offset is to be added in the encoder value so as to match the exact human motion [8]. The best example of this system could be Gypsy 5. It consisted of 17 joints and 37 potentiometers to record their data [9]. Systems inspired by this, like Dexmo [10] are the once which are in use nowdays instead. These systems are for specific body part and also have force feedback which is good in application specific systems. Also there are some systems like [11] which are using the existing systems for various purposes like creation of music.

Advantages – In this system there is no effect of external lighting and no need to worry about external magnetic fields to cause any interference in output. Due to which it doesn't require long recalibration process. This in general makes system easy and productive. System can be used in indoor and outdoor locations.

Disadvantages – As it's a mechanical system it needs to be calibrated often. Here the suit is s bit heavy to wear due to weight of exoskeleton and wires. Due to which freedom of movement can be affected considering other systems. The suit should exactly match the body length. As it is wired the range limitation comes into picture. Mechanical systems on its own cannot identify the direction of motion. It cannot identify self orientation. Plus it cannot record data of jumps as it has no ground awareness.

2) Acoustical system-

This system contains what can be called as a base unit and number of mobile transmitters. This base unit has 3 acoustic receivers. Here RF signals are used to carry out the work so this system can also be called as RF systems. So 3 receivers and multiple transmitters; this is the basic setup of acoustical systems. The mobile transmitters are placed on person's main articulation. The transmitters are sequentially and systematically activated [12]. These produced RF signals are picked up by receivers. The position of each transmitter is calculated by triangulation method which is the same way GPS estimates the position. The triangulation, flight time, direction and velocities of received waves; all this data determines the position of transmitter in 3D space [7], [13].

Advantages – These systems do not suffer metallic interference like optical and magnetic systems.

Disadvantages – Due to sequential firing of transmitters it can create undesirable description of moments sometimes. It is also difficult to obtain correct location on a transmitter at a certain time instant. The cables can reduce the freedom of moment of the person. Here the number transmitter used are also limited. As it's an acoustic system it is very much susceptible to external noises, which makes them very difficult to use. Also the direction of transmitter/receiver affects the system output.

3) Magnetic system-

In magnetic system the sensors are attached to articulated locations on a person's body. These sensors are nothing but magnetic receivers. There is a static magnetic transmitter. The transmitter generates a low-frequency electromagnetic field, with either DC or AC supply. The sensors/receivers location with respect to magnetic transmitter is tracked here [6], [7], [14]. Here both the transmitter and receiver have three orthogonal coils. The intensity of voltage/current on the coils allows the calculation of range and orientation of sensors [3]. Data from sensors i.e. the receiver currents are fed with help of cables to the computer. The sensors record the coordinate data (x, y and z) for its location in 3D space. As we are using magnetic waves so not just the coordinates but the orientation of each sensor with respect to transmitter can also be found out easily [15].

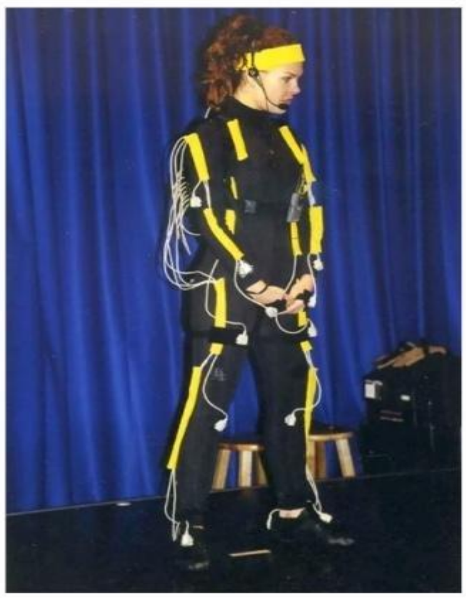

Fig. 3 Performer with Magnetic motion capture suit

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Advantages – The coordinate positions are absolute. It can determine the orientation in space on its own which is really helpful .Data acquired is most of the times immediately usable. This makes it good choice for real time applications. The setup used for data acquisition and processing is cheap and compared to that the accuracy is high.

Disadvantages – can support very small number of sensors. Also the large number of cables collecting data from sensors can hinder the freedom of motion. Systems are very much sensitive to interference from environment (the cement floor or the building pillars have metal rods. This can also effect the systems many time). The workstation location needs to be chosen with very much care due to this. Also the area of setup is very small because as the distance increases, so does the magnetic distortion. The low sampling rate makes its use very much limited. Plus these systems are very expensive in all aspects.

4) Inertial system-

Inertial systems work on 3 major key points and those are inertial sensors, biomechanical models and sensor fusion algorithms. Inertial systems make use of inertial sensors packed together in what are popularly called as the IMUs (inertial measurement units). IMUs typically consists of sensors namely gyroscopes and accelerometers which are two main types of inertial sensors [16]. The combination of accelerometric and gyroscopic sensors is called an inertial measurement unit; each unit can be used separately, or more units can be combined in an inertial sensing suit [14]. Accelerometers detects acceleration and gravitational force. This is then used to calculate change in position relative to gravity (tilt) as well as movement of the IMU through acceleration in any direction. The gyroscope measures angular rate which is used to determine the rotational orientation of the IMU. By combining accelerometer and gyroscope data we can obtain 3-dimensional position and 3-dimensional rotation. Sometimes a magnetometer is also used because the magnetometer measures the Earth's magnetic field or an artificially created magnetic field. This is very useful to orient the IMU. Companies like XSENS has its own XSENS MVN system [17] which is a full body motion capture suit.

Advantages – One of the biggest plus point for these systems is that they are not affected by external factors. The IMUs are self contained units. Day by day its size is getting smaller, with size the power consumption is also dropping. It has very high sampling rates. Also the production cost of these units is very much low and still propelling down. Due to the nature of technology used and all the advantages mentioned above these systems has a great potential for integrating with all sorts of electronic devices

Disadvantages – The data from IMUs is not directly usable. The accelerometers measure the rate of change of the subject and not the position itself. So we have to use combined data of all inertial sensors for that matter. It is done by fusion algorithms and increases the software complexity and adds a bit of calculation delay. These systems are also prone to drift problems.

Fig. 4 Inertial MoCap system by Technaid

B. Optical systems

1) Marker based systems-

These systems contain multiple video-cameras that record the moments of a person from multiple views. That person is attached with markers. The markers can be attached to the skin [14]. There are also full body suits which have markers attached to it; that are specifically designed for motion capture. The suit can be made of spandex or Lycra. The markers can be attached permanently or can be velcroed to the suit of the person [3], [18]. Typically, a system has 6 to 24 cameras. The cameras are strategically positioned around a predefined space to track the marker movements as person moves in that space. The cameras take snaps at short intervals. Each camera generates the 2D coordinates for each reflector, obtained via segmentation. The camera's threshold is adjusted so that only the markers are sampled, ignoring the skin or the fabric of suit. The centroid (geometric centre) of the marker is estimated as a position within the two-dimensional image that is captured. Data of all the cameras are fed to the computer where by suing proprietary software 3D coordinates of the markers are computed by using 2D data from all cameras plus the known dimensions of space and position of the cameras and its orientation in that space [15], [7]. The 3D is only possible when a marker is seen by minimum of 2 cameras at each and every moment during the capture procedure. As many markers are present in the scene at the same time, there are algorithms used that are able to perform the correct association between 2D samples of markers and then track their 3D trajectories throughout the sequences. In addition, since the raw data (once identified) only gives the

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locations of the markers, we have to rely on software to calculate the orientation of the object it is attached to. Now these systems can also be differentiated on basis of type of markers that are used in a system. There are four types of markers as follows.

a) Passive markers-

Passive markers are simple balls (usually of plastic) which are coated with retro-reflective material that reflects the light back so that they are visible in cameras. They reflect the light to cameras rather than generating it, hence the name passive markers. The illumination is typically in the infra-red region, provided by strobes mounted around each camera which are having infra-red filters. The suit on which markers are placed is also sometime a bit reflective so in order to adjust for that a small calibration is done so that only those markers get picked in data and nothing else. Using multiple cameras they are calibrated using an object with reflectors for which the positions of these are known. Marker's complete occlusion, marker swapping, marker identification and markers going outside of the calibration volume are main problems of these systems. One more thing is that infra-red capture works best in a controlled setup [8], [7], [3], [16], [14]. These systems can have frame rates as high as 2000fps. The frame rate for a given system is often treaded off between resolution and speed. Consider this; a 4 megapixel system normally runs at 370 hertz but can run at 2000 hertz for 0.3 megapixels [18].

Fig. 5 Passive markers of different sizes

b) Active markers-

Active markers are light emitting diodes which are powered and cabled. Each LED pulses in a set of sequence, so that each marker is easily identified and easy to track. Here only one LED is turned on at a time. Due to which the acquisition rate will drop proportional to increase in the number of markers [7]. In active markers the light can travel more distance, exactly half more than the passive markers (from camera to marker and back to camera).Since Inverse Square law gives 1/4 the power at twice the distance, with active markers we can expand the capture area compared to passive markers [3].

c) Time modulated active markers-

System with active markers suffers with acquisition rate for large number of markers. In order to overcome this problem a new technique is used. Here time modulation is used, instead of turning one LED on at a time. The result is all LEDs will be turned on at same time, but each will have different (unique) frequency rate of flashing. The markers will convey their unique IDs by modulating their pulses. These are called as time modulated active marker [14], [19]. This is a system redefined by tracking multiple markers over time and modulating the amplitude or pulse width to provide marker IDs. The unique marker IDs reduce the turnaround, by eliminating marker Swapping and providing much cleaner data than other technologies. Here LEDs have on board processing and depends upon radio synchronization. The processing of modulated IDs offers filtered results for lower operational cost. Typically these systems are an eight camera, 12 megapixel spatial resolution 480 hertz system with one subject [18].

Fig 6 MoCap suit with active markers

d) Semi-passive imperceptible marker-

Here the systems do not specifically depend on the light of markers to be tracked. Here tags with photo sensors are used, which are to be detected. Here there is no need for high speed cameras. The system contains photosensitive marker tags which decode the optical signals as the system. As the tags are attached to photo sensors, they can not only compute their own location but also the orientation, incident illumination, and reflectance. There is no compulsion for these markers to be visible to naked eye and can be embedded within clothing. This gives the user freedom of unobtrusive motion [3].

Advantages – These systems provide us with high level of accuracy. The sampling rate for system is also very high. Which makes capture of fast moments possible. The sampling rate of systems is dependent on camera used. If we use high resolution camera, sampling rate will be high. Using this minimum of 200 frames/seconds is easily obtainable. Here one major advantage is that there are no bulky and cables and any other components weighing down a person. So the range and freedom of movement is very

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much natural and combined with high sampling rate, the system has very large use potential.

Disadvantages – Here occlusion of markers is always a problem, if the system is not carefully designed considering all the parameters of it. It can occur in small parts such as hands or closely interacting objects. If the data is not recoverable that can collapse the whole process. This can be overcome with adding more cameras or more markers. But this again increases the software complexity, which will result is high computational time. Even increasing the markers can give birth to marker confusion problems during tracking. This issue can be tackled by using cameras with higher resolutions but then again changing all those cameras will increase the budget of the system. The capture space is also needed to be made such that no light interference is observed on any of the cameras. This in general makes the system very much costly considering its hardware and software. The data is not at all usable in real time as we can imagine the complex processes we have to perform on raw data to get some useful results.

2) Marker less systems-

Marker less motion capture was a result of advancements is computer vision and machine learning. Visual analysis of human motion by computer has been an active topic of research since year 2000. Ever since the beginning many systems were developed. The system applications were different such as: smart surveillance systems, systems for control, systems for analysis, system based on virtual reality and for perceptual interface [20], [21].

These systems are not orthodox in sense of their overall working, but the final output is same. These systems will have different type of cameras used, different number of cameras and different camera configuration. These systems may also differ in the data representations and use of computing algorithms. According to specified requirements these systems will also have different types of model used (or sometimes no pre-defined model is used) to represent human body structure.

Various survey papers cover these methods. In paper [22] reviews about computer vision based methods which are for motion capture and analysis. Here main topics of discussion are model initialization, tracking, pose estimation and lastly action recognition. In paper [23] focus is only on characteristic of motion analysis part. Here the analysis is divided into modeling and estimation. Here the model free approach is discussed separately. In paper [21] the authors have given survey based on human motion analysis. This paper emphasizes on three major points in system that are detection, tracking and behavior understanding. But the simplest classification is given by [24] where the systems are differentiated according to initialization, data processing and pose estimation. Refer [25] for general domain of marker less motion capture systems.

C. Combinational systems

All the optical and non optical systems are very much traditional, in the scene that basic working principle remains the same except some variations may occur either in hardware or software side. Only exceptions are optical marker less motion capture systems where the end goal is same but various systems have various approach for it. But ne can see that any particular system is good in some aspects and but along with that it carries a whole lot of limitations and drawbacks. So a system which makes use of two or more traditional systems called as combined system are created and used.

1) Mechanical exoskeleton with gyroscopic sensors –

A very good example of inertial-Mechanical hybrid system is the Gypsy suit. Gypsy 7 is the latest addition in the Gypsy series by Animazoo. The system comes with its own software modules. If we talk about the suit the exoskeleton suit also comes with 18 control triggers which are in form of buttons and 2 joysticks. The joystick has rubble motors for feedback. These new capabilities give it unprecedented event control. The suit comes with 14 joint sensors with accuracy of 0.125 degrees resolution. Independent digital processing at each joint which factory calibrated joint sensors. The raw weight of suit is just 4kg [26].

Fig. 7 Gypsy 7 system

2) IMU with camera setup –

There are various research papers that focus on this particular type of combination. Here is one system [9] which uses a single digital video camera, a passive spherical marker and an IMU. The controller has a spherical marker mounted on top of it, and an IMU attached to the controller. The marker and the camera system can track and record the position of the 3D controller. The system is able to produce

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detailed 3D positions and orientation information of the controller movements.

Here is another system using same sensors plus camera structure, but this system is specifically designed so that it can be used in outdoor areas. Here [27] system is using 4 consumer cameras and five inertial sensors. Here particle-based optimization scheme is used which makes for tracking in outdoor conditions possible. This system has improved stability and performance with respect to time, which is better than most of the commercial trackers.

3) IMU and tagged markers –

This particular system [28] consists of a one camera (micron Tracker) and one IMU which is firmly joined to the camera. The IMU is made of 3-axis gyroscope, a 3 axis accelerometer and a 3-axis magnetometer. The IMU data is provided as feedback to the main computer at 100 Hz. The camera tracks special patter at 20 fps and 60 ms latency, the data is transferred to the main computer. The system consists of surgical instrument that contains three tracked marker points, which are compactly arranged. There is also a reference frame which has 3 markers and this frame is stationary throughout the working of system. The results of the paper show that the system can work perfectly for long time durations when some of the markers are occluded. Also the system can hold for a short time interval even if all markers are occluded.

III. COMPARISON

Comparison of the basic motion capture systems is presented below in tabular form. The combinational systems are excluded from the comparison because every combinational system is unique and it has its own set of advantages and disadvantages.

Criteria	Mechanical	Acoustical	Magnetic	Inertial	Optical	
					Passive	Active
Cost	Low	medium	Medium-high	Low	Medium-high	high
Hardware Complexity	Low	Medium- high	Medium-high	High	Low	Medium
Software dependency	Low	High	Medium-high	Very high	Very high	Very high
Accuracy	Low	Medium-low	Medium	High	High	High
positioning	Relative	Absolute	Absolute	Relative	Absolute	Absolute
Susceptible to occlusion	No	Yes	No	No	Yes	Yes
Resolution	High	Medium	Low	High	Medium-high	Medium-high
Technology is	Oldest	Relatively Old	Relatively Old	Relatively new	Relatively new	Newest
Setup required for capture site	No	Yes	Yes	No	Yes	Yes (mostly)
Capture site Limited	No	Yes	Yes	No	Yes	Yes
Motion restriction for human performer	High	Medium	Medium	Low	Almost none	Almost none
Needs multiple receivers	No	Yes	Yes	No	Yes	Yes
Calibration needed	Frequently	Initially	Frequently	Initially	Initially	Initially

Table – Comparison of all the traditional motion capture systems

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From the comparison table it is very clear that optical systems are the best performers in all of them. As it makes use of visual data directly the marker positioning is absolute and the biggest advantage of having optical system is its accuracy. As there are no bulky wires or other heavy components attached to the suit, performers can perform naturally without any restrictions which are very ideal for capturing human motion. As optical systems are sensitive to light, it requires a controlled environment to use it. Also the structure of the system requires use of multiple receivers for capturing data all times great amount of hardware is required which makes the system very much expensive to use. Also to keep track of all the markers at all times without any errors, it makes use of various algorithms on large scale. Out of all the systems most of the research and innovation is focused on these systems.

From overall performance standpoint inertial system are just below the optical system. They offer a great deal of accuracy with much less hardware and software. In general the inertial suits or modules are light weight and are far more comfortable than mechanical or magnetic suits. The system is usable in outdoor conditions as well. It is in general less accurate than optical systems but it covers most of its drawbacks. Using application specific algorithms more accuracy can be achieved with inertial systems.

Other systems like mechanical, acoustical and magnetic systems provides a large number of disadvantages, with a very few advantages over the optical and inertial systems. These systems are not often used nowadays. Only when certain application requires a certain set of conditions which are not fulfilled by above conditions, then these systems are used instead.

IV. APPLICATION

A. Video games-

After the initial stages of motion capture success it also made its way into video gaming industry. As the graphics engine evolved overtime, the motion capture technology also evolved in its domain. And since last decade it has become an integral part of gaming industry.

Character design may or may not be inspired by actual human. But to make characters look very much realistic the moves and actions of characters, character interaction with other characters and in game objects are obtained from motion capture. Some games even go one step further to use facial motion capture data, which is fairly repetitively used in animated movies nowadays. After motion capture is done, its checked for errors. If there errors are then it is very much efficient to just reshoot that part instead of trying to fix it with help of graphical software tools. Motion capture is limited to movements that are possible, but it creates natural movements than manual animation and it saves more time. It is true that before shooting there are many things to be done like making a script, casting performance artist, getting rehearsals done before the final shoot. But ultimately motion capture is effective and time saving. God of war, Assassins creed, final fantasy, the witcher, call of duty etc. are some of the famous game series that make use of motion capture.

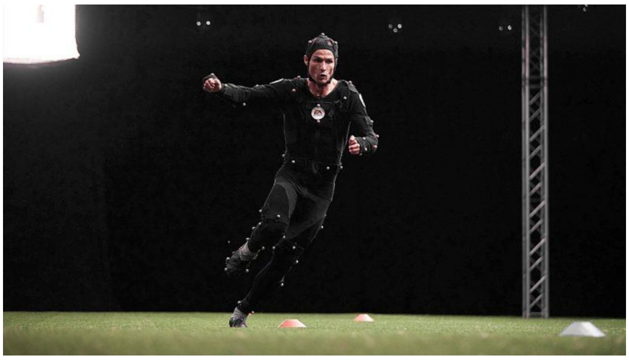

Fig. 8 Cristiano Ronaldo doing motion capture for FIFA game

There is also other category of games where the players use real time motion as the game input to play the game instead of controller. Here the motion data is taken in real time and is integrated with character motion in game, directly or indirectly. A good example would be the KINECT connected to XBOX, where players had to stand in front of KINECT unit and perform actions in order to play the game. There is also Nintendo Switch. But the next best thing in this category is VR gaming. VR games are in its early stages but are showing really good promise for the future. There are various VR modules available in market like HTCVive, PlayStation VR, Oculuc Go etc [29], [30], [31].

B. Sports-

In sports there are two primary methods to analyze motion. One is video-based approach where cameras are used to record the data of players in performance or in training. As soon as the task is completed either it is directly viewed or manual digitization plus software is used to analyze the player, and then the results are drawn and delivered to player. The second approach is use of motion capture technique which provides more in depth and real time data.

Fig. 9 K-VEST system for baseball player analysis

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Each any every sport in the world is associated with a certain skill or skill-set that a player needs to master. If we consider track and field sports, here the skills required are very much limited. There are other games like for example badminton where multiple skills are required. And further more in team sports like cricket the skill set gets even more role dependent and complicated. But not every player is same. So their ability to execute those skills will differ. There are various factors such as body proportions(anthropometry), core strength, hand eye coordination just to name some simple ones and various other complex parameters, they affect the skill execution of each player in different way. Using the motion capture data and with help of various software, the performance can be analyzed. This performance analysis helps in many ways such as finding out body limits, finding out optimal technique for each individual and to upgrade their technique, preventing risk of injury [32], [33], [34].

Data from motion capture can be used for selection of sports equipments and accessories which are optimum for a player. For example [35] describes a system which analyzes golfer's swings and helps in selection of golf club with optimum specification.

This paper [36] gives overview on what type of motion capture techniques are most likely used and for what type of sports they are used for. Also a brief comparison on various systems is given based on the results and methods used in each individual system.

C. Movies and TV shows-

Although the primary idea of motion capture originated in the field of art and entertainment, it took some time for it to make its way into movie industry. Before that motion capture was already in use for study of human and animal motion back in 19th century. Initially it was a tool for understanding biomechanics and was useful even in sports and education field. In 20th century it was possible for animators to use computers for animation and thus the journey of computer generated animation began. Initially animators adopted the known animation techniques such as rotoscoping, but later on the potentiometer were used to capture the data and ultimately it controlled the motion of the computer generated character. Initially the use was limited to animated movie only but as the technology progressed it was also used in non-animated movies as well.

Fig. 10 Actor Andy Serkis in performance for movie

To make characters look even more compelling, hand gestures and facial expression of actors are also recorded and that data is used as base line for animated character movements and expressions. For facial motion capture, nowadays a dedicated setup is used for facial motion capture along with motion capture suit. Same goes for TV shows. Certain fantasy, sci-fi or superhero TV shows make use of CGI, VFX and motion capture which is used in movie industry as well [37], [38].

D. Medical field-

The earliest use of motion capture was in medical field. Before the motion capture, the treatment plan was decided mostly by therapist's observation and visual assessment while patient is performing physical tests. But due to various reasons the human assessment may be inaccurate. This inaccuracy is easily overcome by the motion capture technology.

It is used for medical analysis of patients which are suffering from conditions which makes them motion-impaired. The motion capture data is analyzed and with help of other physical tests the root cause of particular condition is found. This helps in selection of right therapy and effective treatment plan.

Motion capture is also used for rehabilitating patients suffering from injuries. The injuries may be accidental or sports injuries. Every athlete is prone to fatigue and injuries as long as they are playing. The motion capture data is also used for preventing injuries as well as reducing chance of another injury. For example The Sports Medicine Research Laboratory at the University of North Carolina uses motion capture data to study performance of athlete and calculating risk of re-injury.

There are certain unique applications too such as Motor Control Laboratory at Ohio University School of Rehab & Communication Sciences have made a motion capture based virtual dodge ball game. The aim is reduce the fear associated with movements. The game is designed such that it can be changed in real time based on patient's movements so that there range of motion can be increased [39], [40]. Also a game mentioned in [41] called PLAYMANCER is developed for patients with chronic back and neck pain, for assisting in there rehabilitation. Motion capture also helps in studying and analyzing in Orthopedics, Neurology and Musculoskeletal disorders. They are also helpful in taking care of elderly people, as well as people who are physically or mentally disabled [25]. Dedicated systems are designed for these people. For example systems like [42] which is using motion data so that a fall can be detected.

E. Robotics-

Motion capture data plays an important role in robotics where the robot is needed to imitate action or perform a task

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which is human like. The major applications of motion capture in robotics field are programming, activity recognition and design.

In programming a robot aspect, goal is to develop a fast learning robot suitable for mostly industrial purposes. For this research is going on in imitative robotics, which is based on motion capture and machine learning. The robot will analyze the trajectories, extracting key points from it and the robot will follow that path.

Activity recognition is like understanding the data which is provided. After recognition comes the behavior segmentation. For interacting with humans and learning, these two steps are very essential. The design part of robots is also very much derived from motion capture of humans. This can help in many ways like for energy conservation in robot movement, robot stabilization and robot frame design [43].

F. Gait analysis-

Motion capture also gave rise to field of gait analysis. Gait in general can be defined as how someone walks. Gait analysis thus analyses the walking pattern of a person. Like fingerprint and retina structure, gait pattern is also unique for everyone. Hence gait recognition is a great tool for biometric identification. Earlier the problem with this was the inaccuracy of systems. But now as the accuracy has been improved with time the system are very much viable. The main two reasons behind using gait recognition as biometric is that as compared to retina and fingerprint which require high image quality. Gait data can be extracted from low quality video. Also fingerprint and retina scan requires cooperation from subject, which is case of gait recognition can be done from CCTV data too [44], [45].

Along with that gait analysis is used for sports training. It is useful for clinical practices such as clinical diagnosis, healthcare monitoring and rehabilitation. It is also very useful in the field of biomedical engineering [46].

V. Conclusion

This paper discussed motion capture from its history, classification along with advantages and disadvantages of every class and application base of it. Very first system to be used was mechanical system and now latest one is marker less motion capture. No one technique is an all-rounder, each system is perfectly suited for certain situations. This is why combined systems are researched, but the results are not so popular. But out of all the systems, optical systems are the best system in terms of performance and accuracy. Various industries like movie industry, videogame creation, and medical diagnosis are heavily invested in optical motion capture. This resulted in a chain reaction of research and innovation in implementation of these systems. Unlike other systems, optical systems have evolved into various different forms in such a short time span. But the basic setup and hardware cost required makes it viable option for big and wealthy industries only. And also due to its other drawbacks, consumers are making use of inertial or other systems. The current research in optical systems is mainly focused on overcoming those drawbacks and making system viable for all type of consumers.

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