Instantaneous Velocity Measurements for Swimmers to Analyze Athletic Performance

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***Abstract*—The intent of this paper is to introduce a monitoring system for the instantaneous velocity measurements of swimming movements, aiming to provide useful data representation to be used by coaches to analyze the athletes' performance. The basis of the system is using a video monitoring system to record the underwater movements during actual performance of the swimmer and analyze them through numerical data graphical representation of the velocity. The swimmers instantaneous velocity is evaluated versus the swimming movements, this combination gives a clearer and detailed figure of the swimming movements on a timely manner, enabling the identification of the points of strength and weakness in the athletes' performance.**

Keywords*— Sports Engineering, Swimming kinematics, motion analysis, athletic performance measurements.

I. INTRODUCTION

The use of developed engineering technologies has played a key role in improving sports performance in recent years [1]. Nowadays, sports dominancy depends mainly on applying developed technologies in trainings and equipment rather than the athletes' body physical capabilities as in the past. [2]. As a result, applications using advanced technologies are being developed to analyse sports performance to enable more understanding for the athletes' body mechanism and effecting forces on it [3]. Tools for analysis aim to provide useful data information to aid coach knowledge and improve feedback in the development of athletes' performance [4]. While the sports records are improving day by day and the competition between athletes is becoming fiercer, a "fraction of a second" can differ in winning the competition and breaking the record. [5] Scientists are putting more effort and focus on spotting the minimal details that will help in improving the overall performance of the athletes [2].

However the problem is that unlike other sports, in swimming there are few quantitative measures of performance due to the difficulty of the training medium in under water swimming pools, and the high cost of such technologies. [6] Quantitative measures of the swimming stroke characteristics provide reliable data with specific performance metrics to make improvements in performance. Currently these data and measures are not in common use by coaches and athletes, due to the infancy or lack of sufficiently developed technologies [4].

Monitoring systems for swimmers have been a highly focus area for coaches and researchers in the past few years, with the introducing of new technology concepts and reflecting it on the sports industry [7]. The basis of the monitoring systems is to provide performance and capability data for the swimmers, coaches and sport scientist in a timely manner, this data is crucial for developing the personalized training plans for the swimmers [24]. Researches for developing new monitoring systems helped in performance analysis and enhancing swimmers results have accelerated the development of such systems [8]. The basis of the monitoring approaches developed in swimming rely on two main approaches, which use the direct analysis approach or the video based analysis. [9]

A. Direct Analysis Monitoring Approach

Direct analysis is the monitoring approach that measures the performance data through direct connection to the swimmer. In this technique the measurement equipment is kept on the pool with a direct connection to the swimmer in the water. [10] The equipment connected directly to the athlete in the swimming performance transfers the motion inputs into analytical data translated afterwards to numerical graphs and tables [11].

Velocity is measured using the direct analysis monitoring approach by using a cabled system connected between the swimmer and the measuring device [12]. This method has been used and commercialized by SPEED system which was developed by AP Lab [13] using this technique where it is easily assembled and mobilized. However only numerical graph representation is available currently giving a lack of representation of the point of defects in the swimmers performance, depending only on the coach observation [14].

Figure I-1 SPEED system developed by AP Lab, Italy.

B. Video Based Analysis

Video based analysis allows the calculation of various body movement' characteristics through another synchronized software. [5] This could be done by motion analysis of the body movements at certain joints on the body easily captured by the camera and then the software analysis these points movements and calculates the characteristics parameters. This technique made a revolutionary step in the sport analytics field where hundreds of characteristics and data parameters can be analyzed at the same time [15].

Although this is used in many sports, it has been minimally used in swimming due to the limitation of the water environment in the swimming pool where the fraction of light in water leads to miss tracking of the points or markers on the swimmers body, also the interference of water bubbles in the way of these points. There is video based analysis programs for calculating certain elements in the swimming performance, such as Dartfish software [16] used for analyzing the arm strokes glide movement.

The aim of the research is using a combined approach having both the direct analysis and video based analysis approach. This is formed through an image recording process for capturing the underwater swimming movements through the visual input. Simultaneously, using the direct method connected to the swimmer a data input will measure the velocity of performance. The velocity data is computed from the input data to a microcontroller, which feeds it to a computer. Both inputs are compiled and through a developed program presenting the velocity graph and the underwater swimming movements video in same screen.

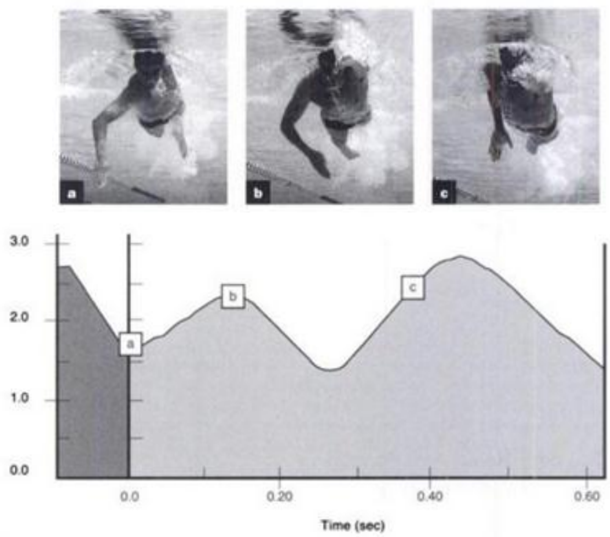

Figure I-2 Velocity graph representation of the swimming body at different movement positions [17].

C. Experimental Work

In the experiment conducted through this research, the physical connection with the swimmer is through a wire cord connected to a belt around his waist to measure the velocity, which does not affect the quality of the swimming performance. The wire cord is connected to a pulley coupled to a taco generator located in the system case at the beginning of the pool. The athlete performs the normal swimming movements while the system captures the data inputs during these movements to process and analyze it. An underwater camera is used for the visual input connected wirelessly to the computer and the measuring system is connected through a microcontroller to the computer that compiles both inputs the developed program.

As the swimmer moves forward the wire rotates the pulley coupled on the generator shaft, which generates a velocity pulse. The voltage generated is directly proportional to the velocity of the swimmers body, so as the swimmers speeds up the voltage output increases. The microcontroller connected to the measuring system receives the input voltage from the taco generator (0–5V) which then computes the analog data to the output pins as digital values. The processing of the data from the microcontroller on the computer will be processed using developed program coded by using MATLAB, to convert the digital input of the microcontroller to a usable numerical data value. These sets of numerical value are transferred to a display form of a graphical representation for the velocity. The camera is connected wirelessly to the computer through Wi-Fi communication method and directly uploads the videos on time on the computer. Furthermore, the developed program compiles the video recording files from the underwater camera along with the velocity graphs into one file as a video where the graph is shown below the video recording of the swimming and both having the same exact execution time.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 11, November-2016

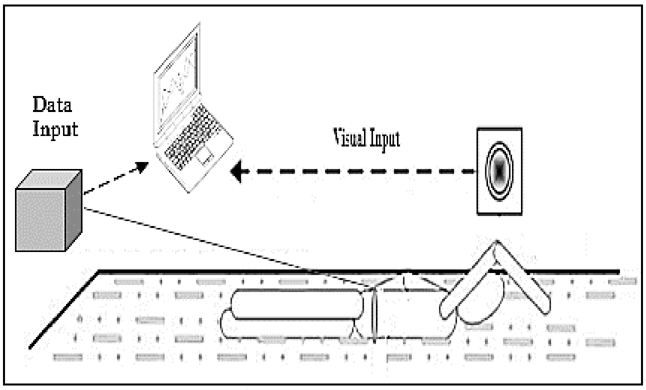

Figure I-3 Representation of the hardware system used in the research.

The measurements are conducted in an Olympic standard swimming pool with lane width of 2.5 meters and depth of 2 meters. The swimming pool edge has to be on a straight line parallel with the swimming lane, while the swimmer starts from in water position. The system is set up in the first lane beside the swimming pool edge to ensure the camera focus on the swimming body with clear image. The system case is assembled on the swimming block of the first lane of the pool with the fixing pins of the case. The microcontroller is connected with a cable to the computer laptop located around 2 meters away from the swimming block to prevent any water splash from coming on it. The camera cart is set up at the beginning edge of the pool, and the camera connectivity and image quality are checked with the computer.

The distance covered by the system is 25 meters of the swimming pool, as this an acceptable distance for measuring any defects of the cycles of stroke characteristics of the athletes. This will give an average of 8 full cycles of strokes for elite athletes in the front crawl swimming technique. The system covers the full underwater movements of the swimming technique, which includes arm motions in stoke cycles, leg kicks, dolphin kicks and streaming at the start of the swimming. This movements can be done separately to define the flaws of each movement separately or combined in the full cycle of swimming.

Figure I-4 Gopro Hero 3+ camera used in the experiment.

The camera records the swimming movements of the athlete under the water. The camera used is the Go Pro Hero 3 specialized in sport video capturing for it high resolution and image processing and suitable for challenging environments. It is completely sealed for underwater usage and easily fixed and angles adjusted on the camera holder. It has 12 Megapixel resolution and curve wide screen aspherical glass lens 170 angle of degree and 21 mm focal length able to capture the smallest details of the movements. The video recording is of 30 fps (frame per second) with 2.7k (16:9) aspect ratio image. It is connected via wireless LAN to the computer and has an internal memory to avoid any missing of data [18].

The cart is the carrier of the camera holder in the experiment. It is easily movable across the edge of the pool aligned with movements of the swimmers. The cart wheels are embedded on the pool edge carves to sustain the straight parallel movement. The camera holder has flexible joints to adjust the camera position according the pool dimensions to be suitable for multiple locations usage.

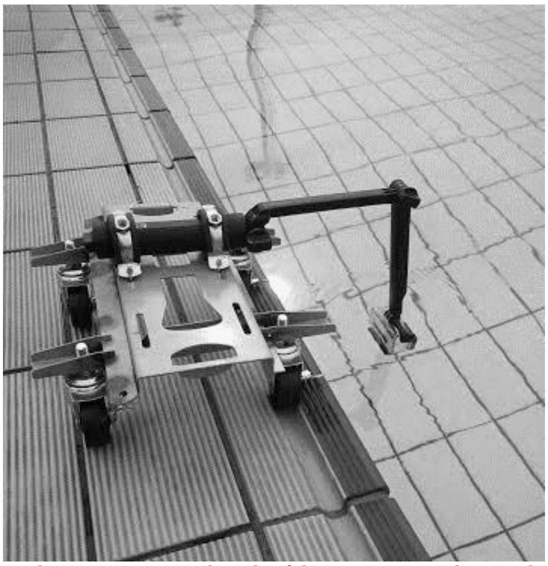
Figure I-5 The cart position on the side of the swimming pool, as used in the experiment.

II. RESULTS AND DISCUSSION

A.

B. Velocity Graph Results

The velocity profile of the athlete across the distance of 25 meters is presented in a graphical representation with the measure of the instantaneous velocity at each point. From the velocity it can be indicated the points of errors and correspond it to the video recording to analyze the exact part of motion movement that lead to this decrease in velocity. The measure of the instantaneous velocity enable quantifying the percentage of error effecting the overall body velocity. Furthermore the velocity profile gives a better understanding for the coach and athlete on the performance with the different swimming movements across the full distance of the race.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 11, November-2016

The graphical representation of the velocity is displayed showing the velocity curve of the body during performance. The graph consists of an X axis representing the Time in Millisecond units while the Y axis is represented the velocity of the swimmer in Meter/second units. The numerical value of the velocity is displayed on the top of graph making it easier to identify the velocity at each point. While the data processing of the velocity calculations could be extracted according to the microcontroller capacity of 16 MHz, the calculations is based on the frame rate of the camera (24 Fps) to enable the synchronization of the data. Thus there is 25 sets of numerical values in the second compiled with the frame rate of the video recording.

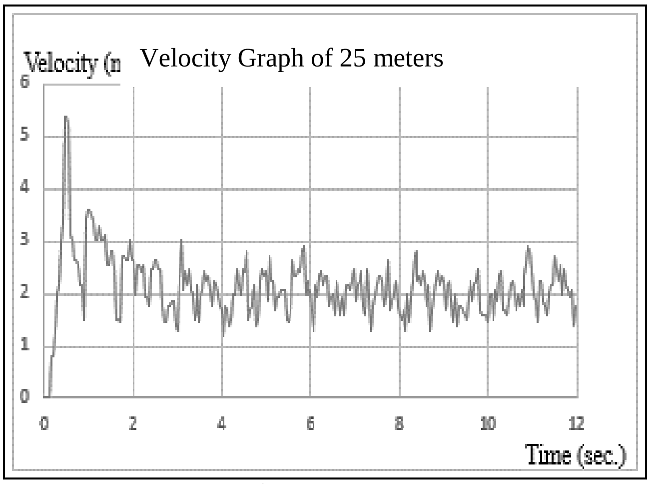

Figure II-1 The velocity graph for the 25 meters swimming measurement.

The measurement was performed on a distance of 25 meters performing the front crawl technique. The average velocity of national level swimmers in the senior age is 2.4 m/s in training conditions which gives 10.4 sec for the distance of 25 meters. The athlete examined had an average velocity of 2.1 meter/sec covering the full distance in 11.9 sec.

The velocity graph shows large percentage of fluctuations between the velocity values, this shows that there is a lot of improvement that can be done on the performance of the athlete. The standard deviation of velocities during the experiment is around 0.373 m/s excluding the pushing the wall and the gliding phase. The ideal performance of a velocity graph for maximum outcome in swimming performance is a semi straight line with minimal disturbances. For world class elite athletes the percentage of fluctuations in instantaneous velocities is around 0.19 m/s. [19].

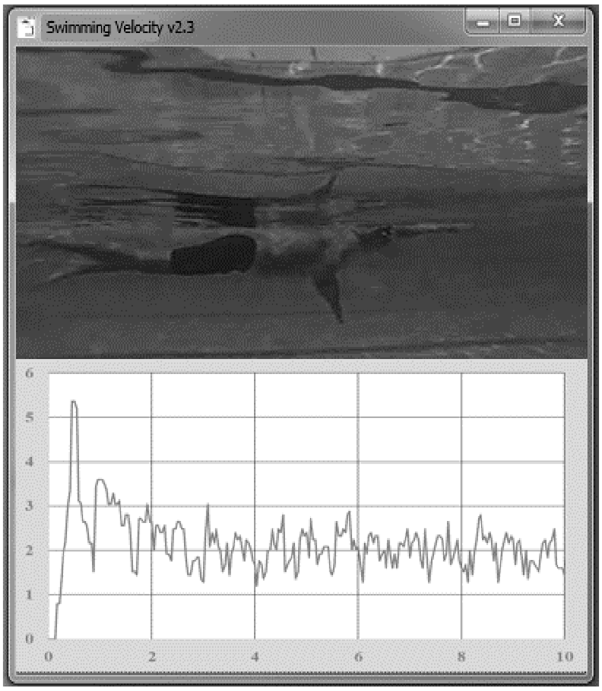

Figure II-2 Program display showing the video recording of the swimmer (top) combined with the velocity graph (bottom)

C. Full distance Velocity Graph analysis

From the output of the instantaneous velocity graph, by detecting the extreme error movements in performance with velocity decrease by +21% from the mean velocity and working on eliminating these points through improvements in training; this will lead to overall enhancement in the velocity average by 14% raising the velocity of the swimmer to an estimate of 2.38 m/s which is almost the average of senior level swimmers. This is an indication of the improvement that can be done through eliminating the extreme error points and its effect on the overall velocity performance.

The next level of improvements is by enhancing the average velocity of the overall performance through working on the power of points of the stroke and decreasing the drag forces on the body. The maximum output of the velocity in the front crawl performance is during the first third of the stroke in the catch phase of the stroke reaching maximum velocities as in Figure II-3, where the body build the momentum at this phase resulting in 40% of the velocity force of the body, so by increasing the power and velocity output in this part of the stroke will lead to improving the performance tremendously.

International Journal of Engineering Research & Technology (IJERT)
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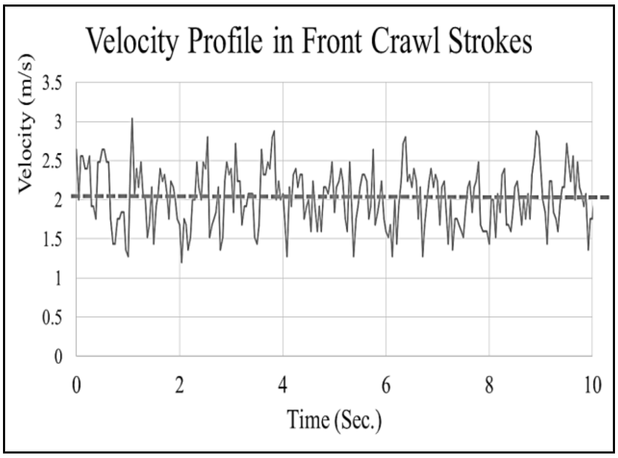

Figure II-3 The velocity graph in front crawl stroke with mean velocity line dotted.

D. Velocity performance of the body in the Stoke Cycle

Swimming consists of repetitive body movements which enable the body floating and the forward movement from the hands and legs pushing forces. The front crawl technique is a form of opposite full hand cycles creating the forward lifting forces with the kicking legs forming the back pushing force. This combination of repetitive movements enables the constant presence of lifting and pushing forces giving the body the needed forward speed. These swimming body movements can be divided into sets of complete cycles, which be respectively divided into units of right and left hand stroke units. The hand stroke unit is the building components of the full body movements' cycle giving a detailed representation of the body behaviors during swimming technique performance.

While the stroke is the key element in the swimming cycle, a detailed analysis is needed to understand the velocity performance of the body during the underwater movement in a single stroke. The analysis of the stroke cycle with reflecting on the overall body velocity will give a detailed representation of the body behaviours during swimming technique performance.

The analysis of the body velocity during the full cycle stroke is based on a set of combined input data representing the velocity of the body and the video recording analysis using tracking identification process in the motion analysis software. This combination will enable a clear identification of the points affecting the body velocity performance through numerical value connections. These data representation will be displayed as: a) Velocity in a graphical chart with the numerical value giving the spontaneous measure of the body velocity. b) Motion tracking of the underwater stroke cycle movements with the motion path analysis that represents the hand movements in the stroke cycle.

The graphical representation of the velocity in the full stroke cycle is displayed showing the velocity curve during the phases of the stroke. The graph consists of an X axis representing the Time in Millisecond units while the Y axis represents the velocity of the swimmer in Meter/second units. The numerical value of the velocity is represented in the table corresponding to the time frame of the movement to identify the velocity at each point. The calculations is based on the frame rate of 42 msec measurements to enable the synchronization of the velocity data with the position and angular displacement data previously calculated.

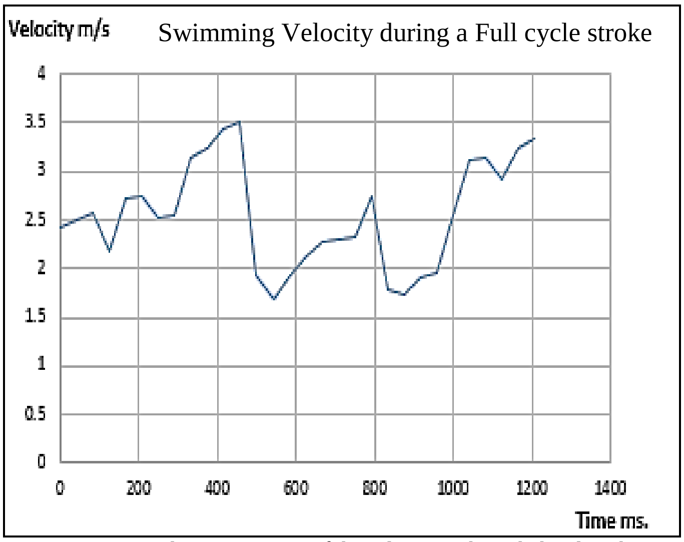

Figure II-4 Graph representation of the velocity in the right hand stroke

The generated numerical data of the velocity during the full stroke represents the turbulence happening on the body velocity through the swimming movement phases. The analysis of the velocity numerical data explains the characteristics of the stroke performance and the points of error. While the average velocity is 2.31 m/s which is reasonable to the average swimming velocities of national swimming athletes, a huge deviation appears between the maximum and minimum velocities compared to the normal average of +15% to +25% in the maximum speed and -10% to -20% in the minimum speed.

The body velocity reaches a peak of 3.52 m/s at the catch phases which correctly corresponds to the phase that generates maximum pushing force. However the deviation between the maximum and the average velocity is higher than normal of +52%. As this higher deviation means that the body generates high pushing force while the swimming body movements fails in keeping the momentum and results in decreasing the overall velocity average. Furthermore, the minimum velocity values shows a 1.68 m/s and 1.72 m/s giving a -27% from the average velocity of the body. The decrease in velocity appears at the transition phases first between the catch and the insweep and then the transition phase between the upsweep and the exiting. These drops in the velocity dilutes the inertia forces of the swimmer bodies and needs higher pushing forces to pick up to the needed average velocity.

E. Points of error in performance in the underwater movements of the right hand stroke

Through the experiment, 3 main points of errors have been identified from the analysis in the motion of the underwater stroke profile. These errors result in the highest decrease in speed and fluctuation in the curvature motion path of the hand movements during the stroke

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ISSN: 2278-0181
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Point 1: The Entry and stretch phase while the hand is entering the water:

As in the motion analysis showing the hand entering the water then a vertical motion of +3 cm happens that is effecting the curvature motion path of the stroke cycle. The velocity of the body drops to 2.18 m/s resulting in a loss of -5% of body velocity in an early stage of the stroke cycle.

Point 2: The transition movement between the down sweep motion and the stroke catch phase:

The motion analysis shows a deviation in the horizontal path of +2 cm and -3 cm as the hand appears to give in a larger inside movement from the wrist angle which then repulses beck to its correct motion. With reflecting on the velocity numerical data it shows a drop of velocity to the minimal level of 1.68 m/s with a total loss of body of velocity of -67% from the catch phase. The conclusion is that during this critical phase of the body collecting to produce the maximum pushing force, any distribution on the motion path creates huge loss in the body velocity.

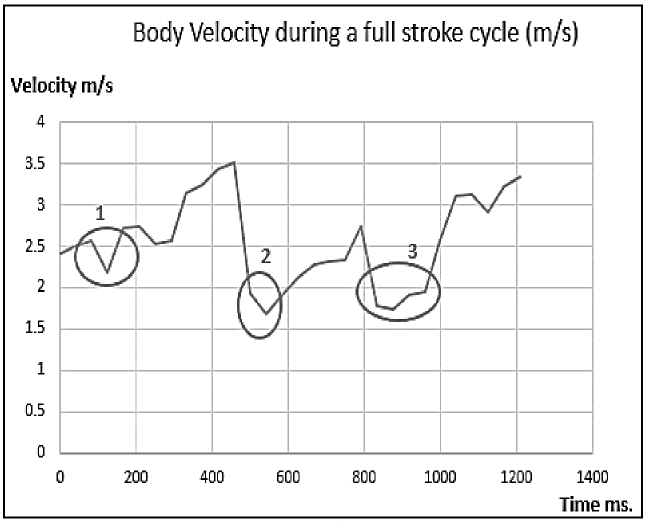

Figure II-5 Graphaical representation of the instatantous velocity in the underwater movement of the right hand stroke, with identification the pionts of error in circles.

Point 3: The point of the upsweep phase of the stroke:

A deviation appears of -4 cm in the horizontal direction of the motion path due to the hand movement is backward the angular movement while unfollowing during the upsweep phase. This resulted in reaching the body velocity of a 1.78 m/s with a loss of -27% from the average body velocity.

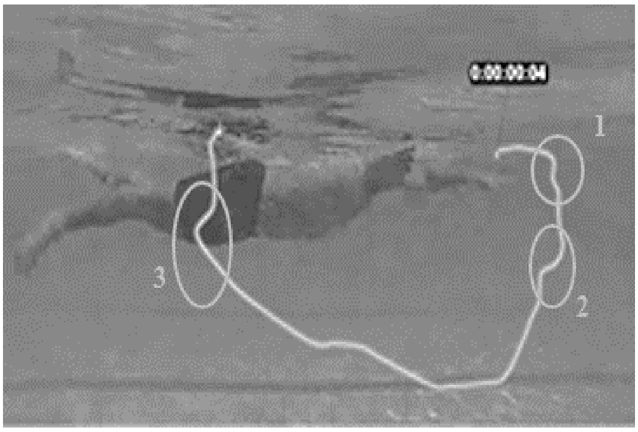

Figure II-6 Points of error in swimming performance identified in the right hand stroke.

III. CONCLUSION

This system enables the identification of the points of error in the athletic performance which enables coach to analyze these points of error and enhance the performance accordingly. The athletic performance of the swimmers is analyzed represented through the instantaneous velocity graph measurements. This graph representation identifies the points of error in the performance at the points of decrease in velocity curve and enables the analysis of this point by the video recording of the swimming movements.

IV. ACKNOWLEDGMENT

The experiment was executed in the Olympic swimming pool of the Shams Sporting Club, Cairo, Egypt. Special Thanks to my friend Mohamed Alaa for assisting in the experiments conduction and to my brother Yosef Nofal for helping in the micro-controller configuration and software coding.

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