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# Sensor fusion: let's enhance the performance of performance enhancement

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#### **Abstract**

Typical in-filed technology used for human movement assessment is a single tool such as a video camera. However, there are drawbacks with this system. Understanding various human actions e.g. swimming kinematics, or the legality of a bowling action in cricket, is important for performance analysis. Inertial sensors can biomechanically capture temporal kinematics. Measuring the kinematics of human movement, allows performance analysers to monitor progression of an athlete's development. Fusing video and inertial sensor technology supplies visual feedback in conjunction with technical information. The video-sensor fusion presented here provides assessment for athletes where gross visual measures combined with fine movement monitoring possible. Therefore, a novel system can be offered which can assist athlete performance development.

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# 1. Introduction

The biomechanical assessment of human movement has been conducted in controlled laboratory environments to enable reliable motion analysis [1, 2]. Laboratory assessment may restrict data capture to small volumes due to restrictions such as limited fields of view of camera systems. Therefore, researchers have used alternative measures such as treadmills for longitudinal capture periods [1, 3, 4].

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However, wearing restrictive garments and/or markers while, for example, attempting to correctly strike a force platform may influence the natural movement patterns [5]. A benefit of controlled environments is the use of more than one technology for biomechanical assessment. A common combination is force platforms and infrared cameras. This provides feedback in two different forms for the same assessment.

Monitoring of movement has long been conducted in the field. While restrictions are present e.g. limited possibilities for 3D assessment, the advent of inertial technology has enabled a greater capacity for analysis. This technology, at least in part, addresses restrictive issues associated with the confines of a traditional laboratory by offering 3D assessment at training and event venues. However, for performance assessment, very few in-field measurement systems are used in conjunction with each other.

Inertial sensors have been used for sport related activity studies. Development and refinement has the technology regularly acknowledged as a viable alternative to video based assessment for many sports including: swimming [6, 7], winter alpine events [8, 9], martial arts sword chop [10], golf [11], and running [3, 12]. While those with an intimate knowledge of inertial sensor capabilities typically understand its data, this can at times, be difficult to communicate to other relevant parties. Additionally, even experienced users with an understanding of plotted inertial profiles may find the data challenging.

Whether assessment is for detailed scientific purposes, or from a coach providing feedback to an athlete, if sufficient quality is not present, the question of the technology's use may come into question. While stating this, it has to be acknowledged that visual feedback is a powerful tool. People respond to visual information that they can relate too [13]. Therefore, video capture should often be considered when collecting data. However, video is not the only method for providing visual information. Inertial sensor technologies provide data that can be presented as graphs, plots, overlays, etc. While each method (video and inertial sensors) has their own positive and negative benefits, combining both can result in a system that becomes a dynamic and more effective assessment and training tool. Development of skills to perform an action, generally results in an increase in performance. Development of motor skills can be dramatic when given feedback to the athlete [13]. Elite athletes appear to refine their skills to a point where their actions a consistently repeatable. While an athlete's actions could not be considered as truly mechanical, or robotic, this repeatability is what is aimed for during technique training. Providing feedback to an athlete assists in this development. This can be by reinforcing the correct action or, highlighting any deficiencies that may exist or be developing within the athlete's technique.

A novel term has recently been coined: Fusion motion capture [9]. This is where the combining of different technologies is carried out to obtain more effective outcomes when analysing data. Fusion of video data with inertial sensor data may benefit both technologies by overcoming shortfalls in each. For experienced researchers, this meshing of technologies may assist in confirming detectable events within the data. For coaches, a tool that may present kinematics in a way that is not possible with a camera alone. The purpose of this article is to report on the development of a tool that adds to the growing area of fusing technologies. This tool can combine video and inertial sensor data.

# 2. Fused technology use

While fused technology has not been widely used for athletic performance assessment, it has been used in the media and subsequently, as an umpiring tool. International television broadcasts pioneered the use of various technologies to provide viewers detailed information for sports such as cricket. Viewing of multiple replays of a controversial incident and shown from just about every conceivable angle as well as various technologies has given the sporting audience a taste of high tech application to sport. A slight nick of the ball as it passes the bat can be seen and heard using various methods. The sport's officials cautiously acknowledged this technology as a possible supportive tool for umpires. Its use is becoming more established as a backup, or referral system in the sport to adjudicate on matters to slight to be

decided on by the umpire's senses alone. Whether a ball nicks the bat, or part of the body can easily be seen using an infrared camera which detects a hotspot on the bat after friction is created by the contact. This in conjunction with synchronised sound recordings builds evidence as to whether the batsman is given out or not out. Officials at international swimming meets use pressure pads on the starting blocks, in conjunction with timing equipment to determine whether a swimmer has broken (left too early) during change-overs in relay events. Fusing technology works in these sporting applications and it is logical that this type of application be developed to assist athletes in enhancing their performance. The sporting audiences benefit from technology fusion, the people that matter i.e. the athletes, should benefit too [14].

In Australian Rules Football, the players can be monitored with fused technology. Inertial sensors combined with GPS are regularly used. Recent developments also incorporate heart rate monitors into this system. These combinations allow coaches and performance analysers to gauge the players performance to make effective judgments on when an interchange (rest periods) should be made. While this has been common in recent years, use of inertial sensor data has been limited. Current research is looking at addressing this issue. Therefore, more accurate player performance is highly likely.

Another area where fused technology can aid in assessment is post-injury rehabilitation. Early post-injury assessment is generally easily carried out e.g. a rolled ankle. Visual feedback after such injury can be made because an altered gait is quite evident. As rehabilitation progresses, the athlete's gait returns towards, their pre-injury pattern. The closer to normal gait, the less pronounced the difference. Due to inertial technology's ability to measure detailed movement signatures, which would most likely not be to be detectable by the naked eye, more accurate assessment can be carried out. Linking this to video, to assist in analysis, will aid rehabilitation professionals to make objective instead of subjective assessments, which are common in this field.

### 3. Freestyle Swimming as an example

Coordination and movement of arm stroke is an important component in freestyle swimming [15]. Approximately 90% of a freestyle swimmer's velocity has been attributed to the effect of arm stroke [16]. While arm stroke is possibly the most critical component (90% velocity contribution) in freestyle swimming, not only is it important to be able to identify arm stroke phases and patterns, it is also important for coordination of arm stroke to body roll and kick patterns. Therefore, coordination of arm stroke and kick, or arm stroke body roll (freestyle and backstroke) coordination are factors that have also been found to be important variables in swimming performance, for all strokes and skill level [17-19]. The ability of inertial sensors to measure multiple segments and in conjunction with the video-sensor fusion interface (displaying the signals) allows for the various coordinations to be assessable with this product. Clear kinematic patterns of segments are present in at least two channels of each relative sensor. From the patterns, temporal measures are possible e.g. timing of arm cycle.

Between-sensor synchronisation allows for timing between left and right limbs to be assessed. Longitudinal capture using inertial sensors also has been shown to detect fatigue [7]. Additionally, symmetry changes in running have been measured using inertial sensors [12]. Due to the ability to capture multiple segments and for extended periods, there is an opportunity to measure various swimming symmetries. While this may not be suitable for the video to be used, the plots in the fused readout provide comparative analysis. Moreover, if fatigue has an affect on any kinematics, it may be assumed that any changes in the signature e.g. timing, magnitude, or symmetry, will be detectable. Again, using the video-sensor fusion tool can provide a quick method for this assessment. Monitoring an athlete's progression through training is critically important [20]. Video-sensor fusion analysis has the potential to be performed relatively quickly e.g. an elite squad with coaching support staff, quite detailed feedback to

athletes could be given before the end of a training session and depending on the type of assessment, even by the end of a training set. This would most likely assist athletes in skill development.

Information about an athlete's action that is visually fed back, results in immediate improvement [13]. This is not restricted to video, but also with all feedback stimuli. If athletes and coaches could observe video images fused with graphical demonstrations of an action e.g. the lateral sweep of a hand, an improvement would be highly likely. This may especially be the case if there are asymmetries present in the swimming action. This process would provide immediate feedback where a swimmer can see what part of their action requires correction. From this, they may immediately alter accordingly while fresh in their mind and then have the changed action collected by the fused systems. Therefore, any benefit, or detrimental outcome can be seen and adjusted/not adjusted accordingly for an improved performance.

Dry-land assessment of swimming kinematics has been carried out [21]. The study found that when simulating freestyle swimming on a swim bench, indicated coordination of body roll was that the hips moved before the shoulders relative to the arm-stroke. However, whether this reflects the freestyle stroke is yet to be proven. Confirmation of the predicted in-water hypothesis by the authors is possible using the fusion technology reported here. Additionally, dry-land measures in laboratory conditions using inertial sensors in conjunction with 3D and 2D camera systems to measure arm-stroke kinematics has also been undertaken [22]. These systems, once synchronised, demonstrated the effectiveness of camera and inertial sensor fusion.

### 4. A Graphical User Interface with novel capabilities

Real life assessment can be challenging. The fusing of video and inertial sensor technologies can overcome some issues faced when capturing data. Synchronisation between video and sensors allows for playback using a Graphical User Interface (GUI). This video-sensor fusion tool is capable of various outputs (Fig 1). Feedback from the video allows for visual analysis of the action. This is typical of any video based system. In addition to video feedback, there are three columns in the GUI that can provide inertial sensor feedback from up to three different sensors simultaneously, or two columns giving data from a single sensor for acceleration and angular velocity. This provides highly technical information of the stroke being observed. Each figure can be inversed in order to compare similar patterns of movement from different segments e.g. the lateral sweep of the left and right hand will have opposite outputs due to the same orientation of the sensors. Therefore, one of the lateral sweep data would be required to be inversed to provide visual similarities during analysis. Visual perception and cognitive processing, known as the Müller-Lyer Illusion, is difficult when data is not presented in a similar manner [23].

Comprehensive video analysis can be time consuming and take up large data space. This is particularly the case with multiple camera analysis. The video-sensor fusion concept reduces this volume, while still providing detailed 3D analysis capabilities. Depending on what assessment was required, the number of sensors required could be as few as one device. This would provide a simple method for capturing intended kinematic measures. By adding more sensors to an assessment, greater and more dynamic assessments would be possible. Therefore, various assessment possibilities can be considered. Moreover, multiple segment analysis is considerably quicker with this method than a multiple video alternative.

Technology fusion is not limited to inertial sensor and video. Bringing together data from many sources is possible and remaining on a swimming theme: Combining vertically mounted force plates to monitor force production with inertial sensor kinematics of a turn and push off would be of immense interest to coaches and analysts. Tethered monitoring systems grouped with inertial sensors, or force plate data may provide accurate force and velocity measures during and after a turn. Heart rate data fused with inertial sensor readings may lead to physiological and biomechanical outputs that show what effects

fatigue has on technique e.g. changes in stroke length, or stroke patterns resulting in possible changes in the symmetry of the swimmer's own swimming stroke signature.

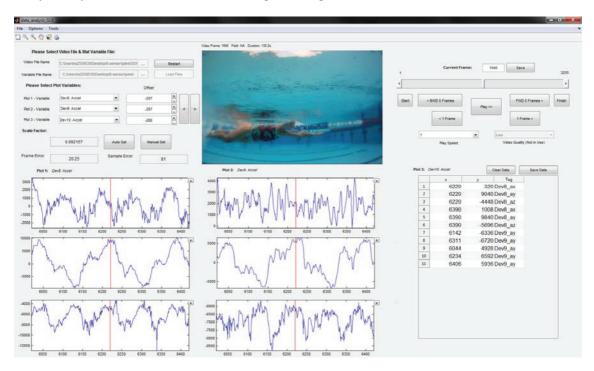


Fig. 1. An example of a video-sensor fusion with spreadsheet function. Any values required can be inserted into the spreadsheet by hovering over that particular point in a plot and choosing. Automatic insertion is carried out

## 5. Conclusion

Fusing video and inertial sensor data allows kinematic analysis from sensor data, while simultaneously confirming the action with the video data. Options of what data and from how many sensors provides for dynamic analysis, from simple methods, through to highly detailed assessment. Alternatively, the system can be used as a learning or teaching tool. Using video-sensor fusion, people with limited experience in inertial sensor technology can relate signal patterns to the video in order to develop an understanding of inertial signals. Therefore, this technology offers an alternative to just video analysis.

By technology fusion, a system has been created that can provide 3D assessment of human movement, without the complexity, cost, physical restrictions of multi camera alternatives. Post data capture assessment can be quick and straight forward, with relatively detailed feedback possible for coaches and athletes in a matter of minutes. The potential is not limited to inertial sensor and video outputs, but many forms of human movement measuring technologies are more than feasible. Therefore, the system takes the next step in athletic performance analysis, by providing a tool that has many uses for coaches, sports scientists, performance analysers, and teachers. From which, athletes will ultimately benefit.

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