The inertial sensor: a base platform for wider adoption in sports science applications

Espinosa, Hugo G; Lee, Jim; James, Daniel A

Espinosa, H. G., Lee, J., & James, D. A. (2015). The inertial sensor: a base platform for wider adoption in sports science applications. Journal of Fitness Research, 4(1), 13–20.
https://research.usc.edu.au/esploro/outputs/journalArticle/The-inertial-sensor-a-base-platform/99449408102621
Document Type: Published Version

INDUSTRY EDUCATION

THE INERTIAL SENSOR: A BASE PLATFORM FOR WIDER ADOPTION IN SPORTS SCIENCE APPLICATIONS

Hugo G. Espinosa[1], Jim Lee[2] and Daniel A. James[1,3]

[1] SABEL Labs, School of Engineering, Griffith University, Brisbane, Queensland, Australia

[2] Physiolytics Laboratory, School of Psychological and Clinical Sciences, Charles Darwin University, Northern Territory, Australia

[3] Centre of Excellence for Applied Sports Science Research, Queensland Academy of Sport, Brisbane Queensland, Australia.

Corresponding author: Hugo G. Espinosa

SABEL Labs, School of Engineering, Griffith University, Nathan Campus, Qld 4111 Australia.

Tel: +61 737358432. Fax: +61 737355198. Email: h.espinosa@griffith.edu.au

ABSTRACT

Introduction: Quantifying human movement during sporting activities is of great interest since it allows trainers to assess the athlete's performance, their rehabilitation and injury recovery. Due to the environment limitations of laboratory testing, research has been focused on the development of Micro electromechanical (MEMS) based inertial sensors with the objective of reducing the sensors in size and power requirements, and making the technology widely available at low cost. The aim of this paper is to present an analysis about the growth of wearable technology, notably, inertial sensors, and the use of a common base platform for different sports application fields including research, education, commercial and servicing.

Methods: The ongoing trends in the inertial sensor technology development through collaborative activity is discussed in this paper. In particular the convergence of several research tools of a three-axial accelerometer/gyroscope and a digital magnetometer, combined with wireless connectivity that allows the control of multiple sensors through a Matlab-based software toolkit are discussed.

Applications fields: The sensor technology has been adopted as an educational tool, as a tool for sports science research, as a base for the development of commercial applications and as a tool that can be used in routing servicing.

Discussion: This paper has examined the growing usage and adoption of inertial sensors in the sports science community, through the vignette of the local development of research tools. It surveyed the current directions of human monitoring using inertial sensors for different sports applications. The research outcomes have subsequently be taken up as commercial products, making sensor use widely available to the general public.

Keywords - Human monitoring, sports, inertial sensors, accelerometers, gyroscopes, magnetometers.

ISSN 2201-5655

INTRODUCTION

From the 1980's, science has played an increasing role in athlete's development and assessment. Initially the major technologies were oriented towards physiological measurement (heart-rate, respiration rate, lactate and other breath and blood analysis)[1,2]. Despite much research and development, most of these measurements can not be made during training or an event. The athlete is required to provide a blood sample or to have sensors attached to the skin or frame. Information is logged by wires to a computer platform.

In recent years, biomechanical measurement has been one major application of new technologies in sport, since it allows, among others, the assessment and monitoring of athlete's performance, injury recovery, rehabilitation and levels of fatigue. Such measurements have been performed for many years in laboratories[3] and in environments where athletes, trainers and scientists have access to the necessary instrumentation and equipment, and the infrastructure is adequate to the training purpose, i.e. a flume used for swimming training[4] or motion capture systems. The earliest techniques used to measure and interpret kinematic chains were multiple video cameras[5]. Such infrastructures can be highly costly and its access can be limited to elite athletes and specialist research teams. Another disadvantage is that the laboratory testing may limit the athlete's performance since in many circumstances the athlete is required to remain quasi static, for example, performing in the capture arc of the video camera system.

In recent years, and with the idea of monitoring athletes in their natural training environment, a small, low cost and portable technology has proven to be as effective as the laboratory testings, where the human movement can be captured, analysed, stored and presented to the athlete and trainer. Such technology relates to wearable inertial sensors and this development has been the focus of much research for more than 10 years[6-8]. These in-house generic monitoring platforms have been widely used in several sports related monitoring applications including, for example, projects in swimming: validation trial of an accelerometer-based sensor platform[9], estimation of energy expenditure[10,4], visualisation of wearable sensor data[11] and velocity profiling[12], in cricket: arm rotation monitoring of bowlers[13], bowler analysis using centre of mass[14], detection of throwing[15] and detection of illegal bowling actions[16], and a variety of other sports projects including race walking[17], trail bike[18], rowing[19], golf[20], tennis[21], basketball[22], field hockey[23], combative sports[24] and video analysis[25,26].

Inertial sensors are micro electromechanical (MEMS) based accelerometers and gyroscopes. The size and cost of these sensors have reduced considerably in recent years, making them an emerging and a very popular resource for biomechanical quantification of health and sporting activities. The connection technologies used by wearable technologies is a useful indicator of emerging trends. Of these, the low power communication protocol Bluetooth has a current user base of 300 million and is set to grow to 3 billion by 2018[27], a 6x growth that is even higher in the wearable sector. Technology development follows a trend called Moore's law[28]. Moore's law was an observation in the mid 1960's that "the number of transistors on integrated circuits doubles approximately every two years". As a flow-on-effect of this law, for any given complexity of a technology (e.g. a sensor), this is especially true for accelerometers[29].

The aim of this paper is to present an analysis about the growth of wearable technology, notably, inertial sensors. In addition, an application to different fields including research, education, servicing and commercial is discussed. Although the application fields presented in this paper are primarily focused on sports applications, the sensor technology has been developed to accommodate projects in different areas including health, rehabilitation and human movement monitoring[30,31].

METHODS

Instrumentation

Wearable inertial sensor technologies for sports applications have undergone continuous changes with the aim of reducing the sensor's size and power requirements, improving its data memory storage and processing power, and making them widely available at low cost.

Basically, the sensors contain two embedded accelerometers and two embedded gyroscopes each of which is capable of measuring acceleration forces of ±10g (g being gravitational force) in two perpendicular directions. This enables collection of data in a three dimensional space. The sensors report a static 1*g* response due to gravity when oriented vertically. Accelerometers measure the time derivative of velocity, so they can be used to measure the dynamics of motion and to determine orientation with respect to the earth's gravity. Gyroscopes measure angular acceleration about a single axis and can be used to determine orientation in an angular coordinate system.

An example of an earlier platform is shown in (Fig. 1a), it consisted of a 3-axis accelerometer with typical dimensions of 52mm × 34mm × 12mm (L×W×H) and weighing approximately 22g. The sensor had limited data storage of 2MB and a limited processing power[8]. It was initially powered using 2xAA batteries, improving it later on with a 240mAh Lithium Polymer (LiPo) battery. Despite the limited features, it was able to be mounted in an arm-band/waist-band for human monitoring and on sports implements such as a hockey stick, cricket bat, tennis racquet, etc.

Second generation platforms typically housed a 3-axis accelerometer and a 3-axis gyroscope[32]. The hardware was designed to fit into a 52mm × 33mm × 11mm (L×W×H) in-house custom-built waterproof package (Fig. 1b). Units were improved with wireless connectivity (2.4GHz RF) and memory storage of 1GB. They included features such as an organic light-emitting diode (OLED) screen (Fig. 1c). Users could record multiple training sessions in different memory ports. Some sensors were made waterproof and often powered with a 90mAh LiPo battery, and enclosures constructed sufficiently robust to resist the impact associated with a variety of sports.

More recently we have seen the development of more generic tools (Fig. 2). Sensor collects data from digital MEMS from the now established 3-axis accelerometer and 3-axis gyroscopes, and now with the addition of other components such as a 3-axis digital magnetometer which works as a digital compass, allowing for the positioning and orientation of a body, based on the earth's magnetic field. This can be used to calibrate both the accelerometer and the gyroscope. Further additions can be expandable ports for adding additional sensors, wireless connectivity (2.4GHz), improved 4GB memory storage, and some units include a Micro SD expansion slot. Platform dimensions are typically 55mm × 30mm × 13mm (L×W×H), a weight of 23g and often powered with a 138mAh high density LiPo battery. Cases are now often injection moulded plastic 2 part case for easy customisation and utility of fit to the human body or sports equipment.

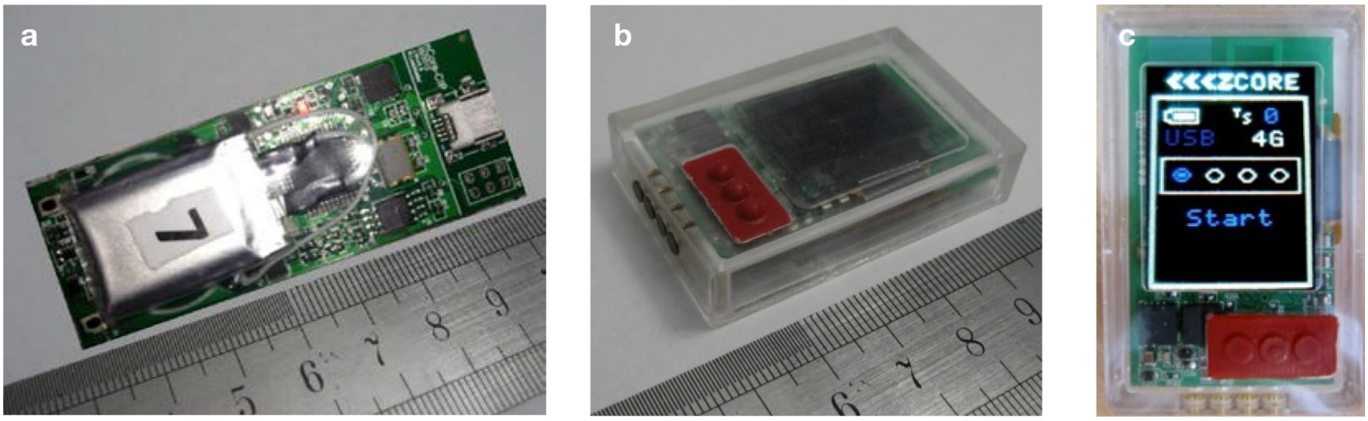

Figure 1 - Evolution of inertial sensors developed with size reduction (a) first generation (b) second generation (c) OLED user interface screen.

Figure 2 - Inertial sensor SABEL Sense.

Graphical user interface

Sensor (including inertial sensor) data can now be stored locally in the sensors, and it can be controlled wirelessly from a remote computer using a Matlab-based graphical comprehensive toolkit (Fig. 3)[32]. From this, devices can be used to monitor athlete's workloads and compare movement patterns from different games or trainings, in order to identify overtraining or undertraining, and ensure, among others, that the athlete's performance during a competition is similar to its training and that the injury recovery is effectively progressing. In addition, the software allows for the control of multiple sensors with no restrictions during data capture, so it can be used to enhance a team's performance. Some of the features of the software include sensor synchronisation, video synchronisation, analysis of sensor data, real-time streaming and sensor calibration.

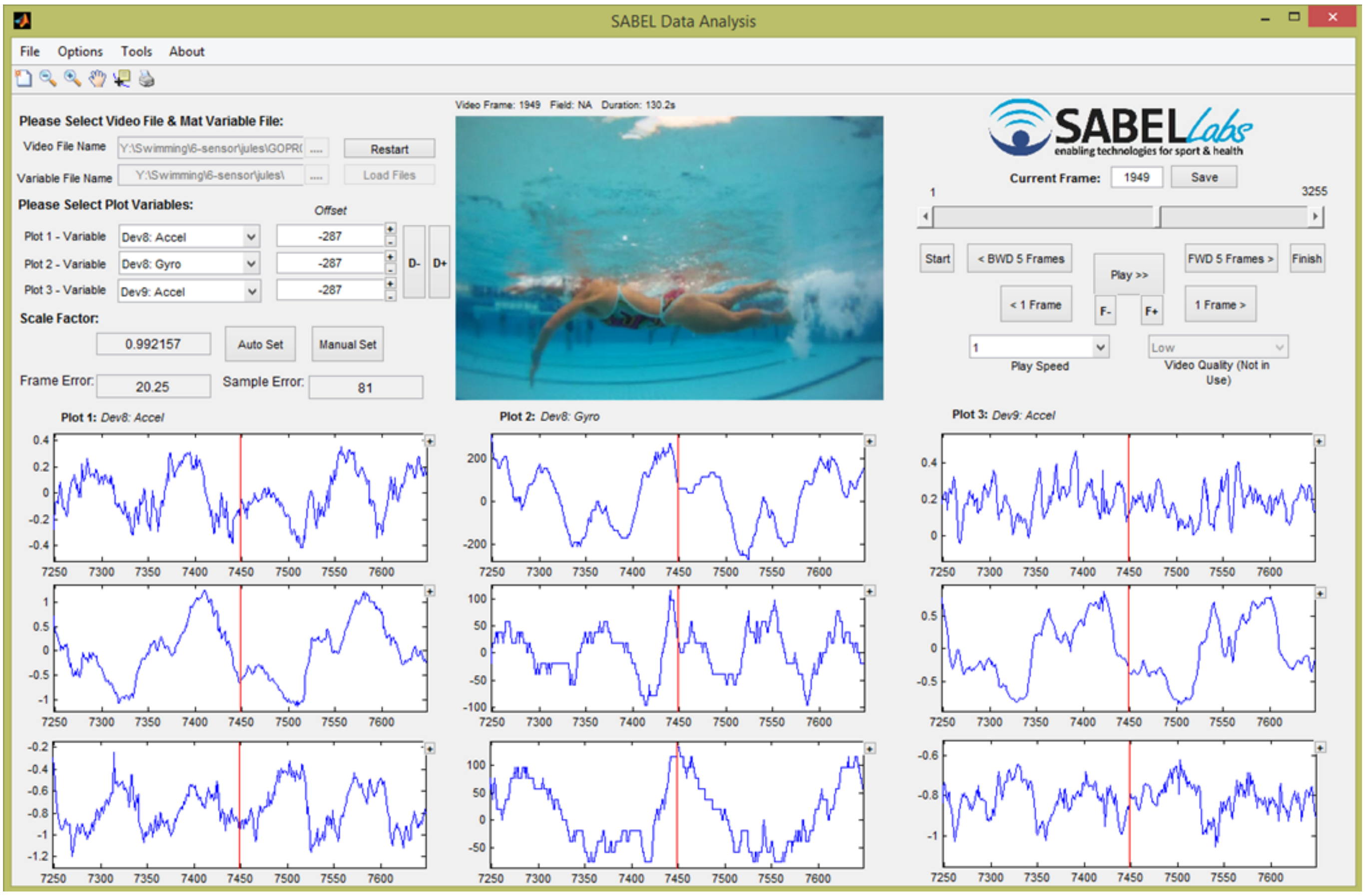

Figure 3 Comprehensive Matlab graphical toolkit.

APPLICATION FIELDS

Having developed a core set of sensors and tools, rapid customisation for specific applications has allowed its application to several contexts. These include its adoption as an educational tool, its use as a tool for sports science research, as a base platform for the development of new technologies as well as a tool that can be used in routine servicing.

Education

Education today requires being able to teach material that is relevant, this includes traditional elements associated with sports as well as emerging areas. The adoption of inertial sensors in sports is doubling every few years. The platform technology has now been used at undergraduate and post-graduate levels in tertiary settings, for the assessments of strength and conditioning exercises as well as assessments of movement competency and control that have relevance to performance and injury prevention. It has been also used for professional develop opportunities for secondary teachers and 'experience and science days' for school students[33]. The tool reduces the barrier to entry to technology through simplistic design and user friendly tools. This allows disciplines such as sports science to have exposure to the technology, engineering disciplines to work in the very engaging context of Sport and secondary education stakeholders to have a taste of an emerging technology.

Research

The tool has been adopted by tertiary institutions, chiefly in the use of the technology as an aid to sports science studies. Whilst several commercial products are available researchers have reported that they are often a combination of cost prohibitive or insufficiently flexible for the research context.

Human movement research using inertial sensor technology at many universities commenced relatively recently. This may be reflective of the growing awareness at institutions that have not been associated with hardware and software development of this technology's capabilities. Studies have included investigations in: race-walking[17] and running gait; and visualisation processes for swimming performance monitoring[11].

Visualisation outputs are important for commercial products[11]. This allows quick and easy assessment of data that enables coaches and athletes effective feedback in order for performance improvement. Identification of differences between an elite and sub-elite athlete in swimming performance was shown to be possible.

Early lifting research is establishing the basis for monitoring of activities. Monitoring in a gymnasium will allow for improvement in technique and allows the opportunity for improving technical skills for competition. A rehabilitation scenario uses sensors for monitoring of the spinal posture when recovering from injury. Related to lifting monitoring has been early investigations into sensor capabilities for monitoring scapula movement. The scapula study has shown that sensors detect scapula movement. While not able to fully track scapula movement, it can detect changes in patterns, therefore possible monitoring of shoulder complex activities such as scapulohumeral rhythm[34].

Validation research into monitoring fatigue is currently being carried out. Results show that sensors are capable of tracking running for extended periods of time and that motion changes detected by an infrared camera system was also detected by the inertial sensors. This validation will allow research to continue to a larger investigation that will look at the effects of fatigue on gait and possible injury outcomes due to detected biomechanical changes.

Research collaborations between Australian and international universities have allowed several interns to undertake research projects using inertial sensors for human monitoring in different sports applications. One example was to determine if acceleration measurements are related to the scores from a professional ballet dancer instructor[35]. It was concluded that accelerometers placed on the sacrum and the wrist are the best indicators of skill level for the demi-plié position, while sensors on the ankle and knee showed poor relationship.

Another example was to present an approach of an automatic system to detect and classify tennis groundstrokes by placing an accelerometer in a participant's wrist. The classification system was able to not only to classify strokes into forehand and backhand, but also into topspin and slice. This is a first approach for an intelligent system that can be used for training enhancement and statistical evaluation of tennis matches. A third example investigated the use of a stick-mounted accelerometer to quantify skill level and development in a group of elite Under 15 and Under 18 hockey players[36]. Hit events and timing differences were used to gain accurate data, and player improvement could be precisely monitored. The resulting accelerometer-based method allowed for more accurate data in which the human measurement error is reduced and the drill can be conducted without supervision and video cameras.

The previous are just some examples of a wide development of sports-related research projects, where interns create techniques that allow inertial sensors to be used as a training aid for players and for coaches to monitor and assess the improvement of the player's skill level.

Commercial

The developed tools and sensors are not intended for commercial application. Their inherent flexibility means they are often neither small enough, polished enough to have wider market appeal. They do however represent a 'hit the ground running' test bed for the development of commercial tools. Recent applications include the development of a wrist band sensor and a biomechanical assessment tool. In the former case the sensor platform enabled the sampling of high rate and detailed data, which could then be altered to synthesise a final design. Additionally key component analysis allowed the minimisation of sensor units and final placement. Thus the sample rate, resolution, filtering and data handling could be used to design a cost and size effective final design. The later involved the customisation of the basic sensor set, experimentation with placement to iterate again to the required sensor set and the addition of high rate sensors was also valuable.

Servicing

The sensors provide a bridge between what is possible and what is practical. Rapid customisation of display outputs allows for applications to key sports of interest. Gageler et al.[37] (2015) applied the technology to the monitoring of jump height in volley ballers. The researchers found that the sensors can measure jump height accurately and this is used as a calculator of athlete workload, which has been reported as a predictor of injury[38,39]. This work demonstrates the utility of the technology as a viable athlete servicing tool for many facets of performance measures.

DISCUSSION AND CONCLUSIONS

The aim of this paper has been to present an analysis about the growth of wearable technology, notably, inertial sensors. This included use different fields including research, education, servicing and commercial applications.

A base platform based on a set of sensors and tools was presented in this paper, together with the current directions of human monitoring using the technology for sports applications in different fields including its adoption as an educational tool at undergraduate and post-graduate levels, its use as a monitoring tool for sports science research, and its recent application as a biomechanical assessment tool in a commercial environment.

Although the fields presented in this paper are focused on sports applications, the sensor technology has been developed to accommodate projects in different areas including health, rehabilitation, injury prevention and human movement monitoring of active lifestyles.

Microsensor development has seen the continual refinement of the technology. The evolution has seen sensors originally designed for research, predominantly in elite sporting applications. The research outcomes have subsequently be taken up as commercialisable products. Therefore making sensor use widely available to the general public. The sporting application progression has been seen in rehabilitation, again predominantly in sport but also in general populations. It appears to be logical that inertial sensor use be taught within biomechanics based teachings within sport and exercise science degrees.

ACKNOWLEDGEMENTS

The authors acknowledge the financial support of Griffith University Enterprise Innovation Fund to develop the SABEL Sense technology and support of collaborating institutions.

REFERENCES

1. Heath, G.W., Hagberg, J.M., Ehsani A.A. & Holloszy, J.O. (1981). A physiological comparison of young and older endurance athletes. *Journal of Applied Physiology, 51,* 634-640.
2. Gore C.J. (2000). *Physiological tests for elite athletes*, Australian Sports Commission, Champaign IL, Human Kinetics.
3. Hawley, J. (1999). *Gudelines for laboratory and field testing of athletic potential and performance, Basic and Applied Sciences for Sports Medicine.* edited by Maughan, R.J., Butterworth-Heinemann, Oxford.
4. Nordsborg, N.B., Espinosa, H.G. & Thiel, D.V. (2014). Estimating energy expenditure during front crawl swimming using accelerometers. *Procedia Engineering, 72*, 132-137.
5. Franks I.M., & Nagelkerke, P. (1988). The use of computer interactive video in sport analysis. *Ergonomics*, *31(11)*, 1593-1603.
6. James, D.A., Davey, N. & Rice, T. (2004). An accelerometer based sensor platform for insitu elite athlete performance analysis. *Proceedings of IEEE Sensors*, 1373-1376.
7. James, D.A. (2006). The application of inertial sensors in elite sports monitoring. *The Engineering of Sport 6*. Springer New York, 289-294.
8. Davey, N., Wixted, A.J., Ohgi, Y. & James, D.A. (2008). A low cost self contained platform for human motion analysis. *The Impact of Technology on Sport II*, 101-111.
9. Davey, N., Anderson, M. & James, D.A. (2008). Validation trial of an accelerometer-based sensor platform for swimming. *Sports Technology, 1(4-5)*, 202-207.
10. Wixted, A.J., Thiel, D.V., Hahn, A.G., Gore, C.J., Pyne, D.B. & James, D.A. (2007). Measurement of energy expenditure in elite athletes using MEMS-based triaxial accelerometers. *IEEE Sensors Journal, 7(4)*, 481-488.
11. Rowlands, D., James, D.A. & Lee, J.B. (2013). Visualization of wearable sensor data during swimming for performance analysis. *Sports Technology, 6(3)*, 130-136.
12. Stamm, A., James, D.A. & Thiel, D.V. (2013). Velocity profiling using inertial sensors for freestyle swimming. *Sports Engineering, 16(1),* 1-11.
13. Espinosa, H.G., James, D.A. & Wixted, A.J. (2013). Video Digitising Interface for Monitoring Upper Arm and Forearm Rotation of Cricket Bowlers. *Proceedings of ASTN, 1(1),* 24.
14. Rowlands, D., James, D.A. & Thiel, D.V. (2009). Bowler analysis in cricket using centre of mass inertial monitoring. *Sports Technology, 2(1-2)*, 39-42.
15. Wixted, A.J., Portus, M., Spratford, W. & James, D.A. (2011). Detection of throwing in cricket using wearable sensors. *Sports Technology, 4(3-4),* 134-140.
16. Wixted, A.J., Portus, M. & James, D.A. (2010). Virtual & inertial sensors to detect illegal cricket bowling. *Procedia Engineering, 2(2)*, 3453.
17. Lee, J.B., Mellifont, R.B., Burkett, B.J. & James, D.A. (2013). Detection of Illegal Race Walking: A Tool to Assist Coaching and Judging. *Sensors, 13(12)*, 16065-16074.
18. Cutmore, T., Brabant, M., Neumann, D., Lee, J.B., Leadbetter, R. & James, D.A. (2013). Using Sensor Technology to Assess Health and Sport Benefits of Trail Bike Riding and Other Off-Road Motorcycling Activities: A Research Proposal. *Proceedings of ASTN, 1(1)*, 33.
19. Lai, A., Hayes, J.P. & James, D.A. (2005). A Single-Scull Rowing Model. *Australasian Sports Technology Alliance.*
20. Kooyman, D.J., James, D.A. & Rowlands, D. (2013). A Feedback System for the Motor Learning of Skills in Golf. *Procedia Engineering, 60*, 226-231.
21. Ahmadi, A., Rowlands, D. & James, D.A. (2009).

Towards a wearable device for skill assessment and skill acquisition of a tennis player during the first serve. *Sports Technology, 2(3-4)*, 129-136.
22. Kirkup, J.A., Rowlands, D. & Thiel, D.V. (2014). Dynamic tracking of a 2.4 GHz waist mounted beacon for indoor basketball player positioning. *Procedia Engineering, 72*, 108-113.
23. Tremayne, M., Thiel, D.V. & Nottle, S. (2011). Accelerometer measures of field hockey skills development. *Sports Technology, 4(3-4)*, 122-127.
24. Partridge, K., Hayes, J.P., James, D.A., Hill, C., Gin, G. & Hahn, A. (2005). A wireless-sensor scoring and training system for combative sports. *Smart Materials, Nano-, and Micro-Smart Systems. International Society for Optics and Photonics,* 402-408.
25. Rowlands, D., McCarthy, M. & James, D.A. (2012). Using inertial sensors to index into video. *Procedia Engineering, 34*, 598-603.
26. Espinosa, H. G., James, D. A., Kelly, S. & Wixted, A. (2013). Sports monitoring data and video interface using a GUI auto generation Matlab tool. *Procedia Engineering, 60*, 243-248.
27. Carlaw, S. (2013). *Emerging Bluetooth Verticals*. Bluetooth World Shanghai.
28. Schaller, R. R. (1997). Moore's law: past, present and future. *Spectrum, IEEE, 34(6)*, 52-59.
29. Walter, P. L. (1997). The history of the accelerometer. *Sound and vibration, 31(3)*, 16-23.
30. James D.A., Thiel D.E., Allen K.J., Abell B., Kilbreath S.L., Davis G.M., Rowlands D. & Thiel D.V. (2012). Technology and health: Physical activity monitoring in the free living environment. *Procedia Engineering, 34*,367-372.
31. Thiel, D.V., Espinosa, H.G., Davis, G.M., Dylke, E., Foroughi, N. & Kilbreath, S.L. (2013). Arm movement: The effect of obesity on active lifestyles. *Procedia Engineering, 60*, 182-187.
32. James, D.A., Leadbetter, R.I., Neeli, M.R., Burkett, B.J., Thiel, D.V. & Lee, J.B. (2011). An integrated swimming monitoring system for the biomechanical analysis of swimming strokes. *Sports Technology, 4(3-4)*, 141-150.
33. Espinosa, H.G., Lee, J., Keogh, J., Grigg, J. & James, D.A. (2015). Use of inertial sensors in educational engagement activities. *7th Asia-Pacific Congress on Sports Technology (APCST)*, Sept 2015.
34. Lee, J., Gordon, S., Land, H., Leadbetter, R. & James, D.A. (2013). An effective method for monitoring swimmers with a shoulder injury. *Proceedings of ASTN, 1(1)*, 30.
35. Thiel, D.V., Quandt, J., Carter, S.J. & Moyle, G. (2014). Accelerometer based performance assessment of basic routines in classical ballet. *Procedia Engineering, 72*, 14-19.
36. Tremayne, M., Thiel, D.V. & Nottle, S. (2011). Accelerometer measures of field hockey skills development. *Sports Technology*, *4(3-4)*, 122-127.
37. Gageler, W.H., Wearing, S. & James, D.A. (2015). Automatic jump detection method for athlete monitoring and performance in volleyball. *Journal of Performance Analysis in Sport*, In press.
38. Vetter, R. E., & Symonds, M. L. (2010). Correlations between injury, training intensity, and physical and mental exhaustion among college athletes. *The Journal of Strength & Conditioning Research*, *24*(3), 587-596.
39. Brooks, J. H., Fuller, C. W., Kemp, S. P., & Reddin, D. B. (2008). An assessment of training volume in professional rugby union and its impact on the incidence, severity, and nature of match and training injuries. *Journal of sports sciences*, *26*(8), 863-873.