IN-FIELD USE OF WEARABLE MAGNETO-INERTIAL SENSORS FOR SPORTS PERFORMANCE EVALUATION

Valentina Camomilla[1], Elena Bergamini[1], Silvia Fantozzi[2], Giuseppe Vannozzi[1]
Interuniversity Centre of Bioengineering of the Human Neuromusculoskeletal System, University of Rome "Foro Italico", Italy [1]
University of Bologna, Bologna, Italy[2]

Aim: to systematically review the articles using accelerometers, gyroscopes and/or magnetometers to analyse motor tasks of interest in a sport context performed by athletes. *Data Sources*: Web of Science, Scopus, Pubmed, and Sport Discus databases (until May 2014). *Study Selection*: 130 studies were selected after excluding duplicates and studies dealing with risk of injury, physical activity, and energy expenditure. *Data Extraction*: Data included characteristics of sport, athletes, sensor spot check, calibration and fixing, experimental setting. *Data Synthesis*: Magneto-inertial sensors are mainly used in competition or in-field settings, to assess motor capacity or technique of elite athletes. Technical guidelines to better acquire, analyse and interpret data within the limits set by the sensors were provided.

KEYWORDS: inertial measurement unit, systematic review, sports biomechanics.

INTRODUCTION: A successful coaching outcome can be supported by useful and timely feedback to the athlete to target performance defects. A systematic, objective and reliable performance monitoring and evaluation, performed by means of qualitative and quantitative analysis of mechanical variables that determine performance, can reinforce the link between research and coaching practice, especially in élite sports. An alternative to classical laboratory-based assessment is the use of magneto and inertial sensors that can measure movement-related data, linear and angular motion, without any space limitation and no cumbersome setup (Armstrong et al., 2007, Dellaserra et al., 2014). New generation of inertial sensors are portable, cheap, easy-to-use and allow to perform activities during training or competition, opening new perspectives in sport sciences. Recently, the use of wearable inertial sensors have been analysed in swimming (Magalhaes et al., 2014), running (Norris et al, 2014), and for strength and ballistic assessment (Mc Master et al., 2014). However, this literature does not provide a general overview of the spreading in the use of magneto and inertial sensors through different sports disciplines. Moreover, no general good practice rules about the use of these sensors can be derived from the existing literature for sports biomechanics analysis. This abstract provides general information derived from a systematic review of the literature that aims at filling this gap, identifying and evaluating current evidence for the use of magneto and inertial sensors for performance evaluation. It discusses some of the deficiencies in existing research, highlights the potential for the use of inertia-based instrumentation into an in-field sport setting, suggesting guidelines for a better exploitation of such potential.

METHODS: *Gyroscope, accelerometer and magnetic sensors:* MEMS gyroscope, accelerometer and magnetic sensors provide, respectively, the values of the angular velocity, the sum of gravitational and inertial linear accelerations, and the local magnetic field vector components, about and along their sensing axis/axes. Single-, two- or three-axis sensors exist. The unit orientation is commonly provided as a further output of the device. Although all three sensors can be used, individually, to obtain information about the orientation of the rigid body where they are fixed, this variable is not directly measured by any of them, but rather estimated by sensor fusion algorithms are designed to cope with the different sources of error effecting the sensors (like gyroscope bias drift, inertial acceleration, magnetic field distortion) by exploiting the complementary properties of the sensors. To improve the accuracy of 2D orientation estimation, gyroscopes and accelerometers are often combined in an Inertial Measurement Unit (IMU). If 3D orientation is needed, magnetic sensors are also embedded in a Magnetic and Inertial Measurement Unit (MIMU). MIMU data can be used to estimate different parameters, based on feature detection in the measured signals, or on more sophisticated processing techniques able to properly combine the information provided by two or more sensors.

Systematic review in- and exclusion criteria: Studies published in English as full papers including works that use magneto-inertial sensors to analyse motor tasks of interest in a sport context and performed by athletes were considered. Works dealing with the assessment of motor capacity, or of performance related and refereeing parameters were included, while those dealing with workload, oxygen uptake, metabolic cost, activity monitoring, and risk of injury were excluded. *Search strategy:* The review of the literature was performed by selecting articles from Web of Science, Scopus, Pubmed, and Sport Discus (until May 31st 2014). Keywords were selected to define the measurement instruments, the sport activity performed, the subject tested and to exclude studies dealing with patients or risk of injury, and assessing physical activity or energy expenditure. Keyword search was performed in the title, abstract, or keywords fields. Additional relevant papers were thereafter identified by examining the reference lists of papers identified from electronic searching. *Review process:* Conference proceedings, theses, and duplicate journal references were removed from the 661 retrieved documents and selection criteria used to select 99 studies for detailed review. Title and abstracts of the retrieved papers were subsequently evaluated for inclusion by two independent reviewers (E.B. and V.C.). A full text evaluation and consensus meetings of all authors were performed when required. The 99 selected papers were manually screened, to include 31 further eligible studies (Fig. 1).

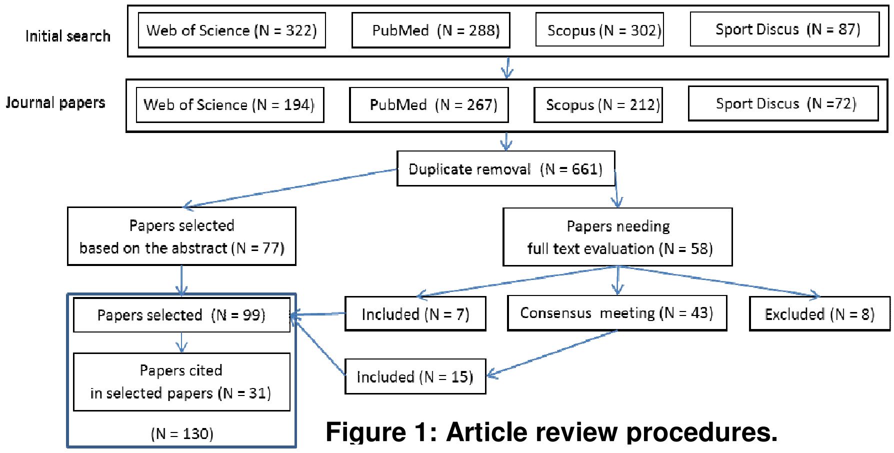


Figure 1: Article review procedures.

RESULTS: The papers have been published in 49 different journals, 60% of them appeared in only 9 journals (Fig. 3). Trends of publication along the years are also shown. MIMU confirmed their potential as in-field instruments, adequate to study elite performance (Fig.3). Based on possible positioning and configurations depicted in Figure 2, temporal parameters (phase identification, foot contact timings, stride/step/stroke duration and frequency), linear and angular kinematic variables (position/orientation, and linear/angular velocity and acceleration), and linear and angular dynamic parameters (lower body/leg stiffness, joint forces, moments, and powers) were extracted.

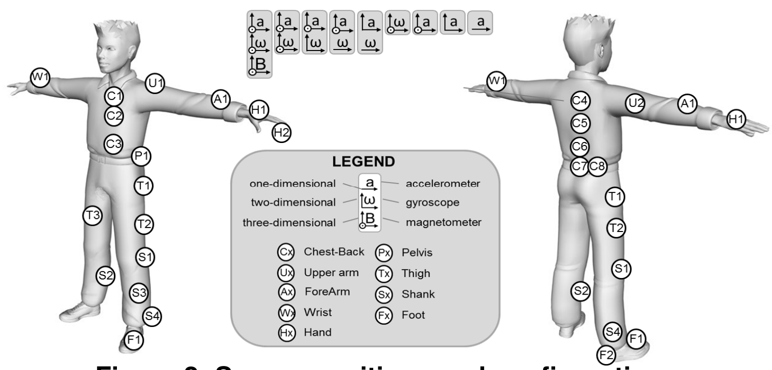
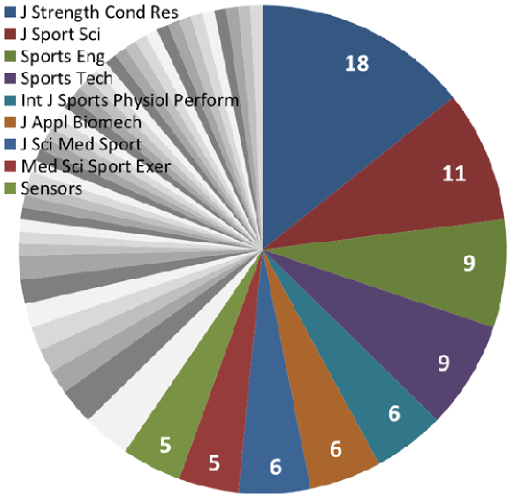
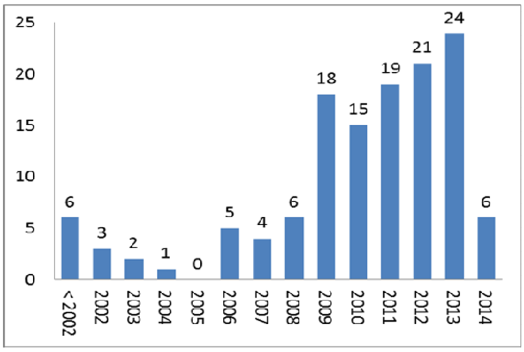


Figure 2: Sensor positions and configurations.





Athletes	
Elite	39%
Sub-elite	26%
Recreational	27%
not specified	8%

Setting	
in field	57%
competition	5%
laboratory	34%
not specified	5%

Figure 3: Papers distribution over journals and time, athletes and setting type.

team sports		*other individual sports*		*cyclic sports*		*winter sports*	
rugby	9	tennis	4	distance running	24	snowboarding	4
Australian football	5	golf	3	sprint running	2	ski jumping	4
soccer	2	shooting	1	swimming	10	alpine skiing	5
cricket	2	fencing	1	cycling	4		
baseball	6	bowling	1	kayaking	2	*training*	
field hockey	1	boxe	1	rowing	7		
basketball	1	diving	1			wheelchair sports	3
ice hockey	2	shot-put	1			weight training	13
netball	1	karate	1			jumping	8

Figure 4: Sports where sensors have been used.

DISCUSSION*:* Literature was analysed and relevant guidelines were defined as regards the following aspects: technical literature is rich of examples of possible guidelines (*e.g.* Bergamini et al., 2014), however, the use of *spot_checks* to assess the quality of the original/embedded calibration is rarely if ever performed in applied literature. MIMU *calibration* was rarely performed; the most used technique was the six-point method of Lai et al. (2004). *Anatomical calibration* was seldom performed to relate the output variables to the anatomy, mainly when assessing joint or segment kinematics. For pelvis and trunk segments, the MIMU is typically aligned with gravity during a neutral standing posture. Rarely, either a functional or a point-based calibration were used. Different indications regarding the *fixing technique* and *position* were given depending on the sport analysed. For running, the most frequent sensor position was on the foot (onto rigid and non-deformable parts of the shoe in order to limit external oscillations) and on the trunk, since the position on the shank may affect accuracy of toe-off and heel-strike determination. For swimming, there is no consensus on whether wrist or sacrum positioning should be preferred. In general, sensor fixing were chosen mainly to avoid restricting the range of movement, while possibly limiting the movement between body and device. *Data processing* included low-pass filtering with various cutoff frequencies depending on the sport analysed. The orientation drift due to gyroscope static and dynamic noise integration was rarely acknowledged and, in this case, compensated mainly by subtracting average trend curves or relying on sensor fusion algorithms embedded in the acquisition software. Finally, ferromagnetic disturbances are generally ignored although of course not relevant in outdoor conditions. *Validation* is carried out mainly in methodological contributions and often no information is provided about validity and reliability of the estimated parameters.

Table 1
Guidelines for MIMU use in sports

Quality assessment
1. avoid ferromagnetic sources when possible (no iron or magnetic fields)
2. assess MIMU accuracy through spot check
3. report or assess the accuracy of the analysed curves or parameters
Calibration
4. perform sensors re-calibration, for poor accuracy
5. perform anatomical calibration, for comparison within and between subjects
Fixing
6. take care for MIMU fixation to limit the movement between body and device (avoid tape)
7. for tasks entailing impacts, possibly avoid elastic belt for fixing and cumbersome devices
8. avoid areas with “wobbling” soft tissues (fat or muscles) and areas close to joints
Data Processing
9. correct the gyroscope static bias
10. filter electronic noise
11. use *ad hoc* algorithms to compensate for dynamic sensor drift
12. interpret data within the limits set by the quality assessment

CONCLUSION*:* MIMU devices have the potential to monitor human movements continuously, representing a reliable tool for in-field performance assessment that could support coaching practice. Future studies should focus on filling the gap that still keep coaches and practitioners far from this technology. In this respect, sport biomechanists and engineers could work more on incorporating additional basic scores and further variables widely used in the field into the current experimental setups involving MIMUs.

REFERENCES:

Armstrong, S. (2007). Wireless connectivity for health and sports monitoring: a review. *Br J Sports Med*, 41(5), 285-9.

Bergamini, E. & al. (2014). Estimating orientation using magnetic and inertial sensors and different sensor fusion approaches: accuracy assessment in manual and locomotion tasks. *Sensors*, 14(10), 18625-49.

Dellaserra, C.L. & al. (2014). Use of integrated technology in team sports: a review of opportunities, challenges, and future directions for athletes. *J Strength Cond Res*, 28(2), 556-73.

de Magalhaes, F.A. & al. (2014). Wearable inertial sensors in swimming motion analysis: a systematic review. *J Sports Sci*, 33(7), 732-45.

Lai, A. & al. (2004). Semi-automatic calibration technique using six inertial frames of reference, In *Microelectronics: Design, Technology, and Packaging*; Proceedings SPIE, 5274, 531-542.

Mc Master, D.T. & al. (2014). A brief review of strength and ballistic assessment methodologies in sport. *Sports Med*, 44(5), 603-23.

Norris, M. & al. (2014). Method analysis of accelerometers and gyroscopes in running gait: A systematic review. *Curr Sports Med Rep*, 8(3), 136-41.