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# The role of science and technology in sport

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**Abstract**

Wearable devices measuring some physical or physiological quantity of an individual have already become a part of daily life for many people. While such simple devices output mainly the statistical values of measured quantities or count events, demands in sport are more stringent. Quantities of interest must be measured in wider range, with greater precision, and with higher sampling frequency. We present a short introduction to motor learning in sport and its needs for technology back-up. We present properties and limitations of various sensors used for sport activity signal acquisition, means of communication, and properties and limitations of communication channels. We shed some light on the analysis of various aspects of sport activity signal and data processing. We present timing, spatial, and computational power constraints of processing. Attention is given also to the state of the art data processing techniques such as machine learning and data mining. In conclusion we present some technological trends and challenges in sport, such as Internet of Things, smart sport equipment, and real-time biofeedback systems and applications.



*Keywords:* motor learning; sensors; sport activity signal acquisition; biofeedback system; sport data analysis; smart sport equipment

## 1. Introduction

Physical activity is becoming an increasingly important aspect of our lives. It is a necessary and a required ingredient of a healthy life and there is no doubt that it contributes to our wellbeing. While sport used to be a

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synonym for physical activity performed in a person's free time that might not be true anymore. We can roughly categorize the free time physical activity into recreational sport or recreation, amateur sport, and professional sport. Each of the three categories has a separate place in the society and includes people with different goals. But one thing is common to all of them; the need and the urge for the quantification of their physical activity [1].

Technology used in sport is developing very fast; recent day technology possesses properties and functionality only imagined a few years ago. For example, in the past the motion of gymnasts could only be analyzed in certain detail through video recordings, while at present gymnasts can wear a suit with motion sensors [2] that records their moves. Based on the athlete's kinematic model such systems can give a detailed analysis of their motion in three-dimensional space. Similar examples could be found for other sports.

In recent years a number of inexpensive toys and gadgets aimed for activity tracking have been introduced to the market. Gadgets, such as wrist bands, give statistical parameters and count events of a particular physical activity. For example, they count the number of steps made during the day, they can detect falls, they can monitor sleep quality, etc. Such gadgets usually acquire movements or physiological processes of the user with low frequency and low precision, what is at the end good enough for their intended use. At the other end of sport technology are complex and expensive systems that simultaneously gather and process large amounts of data. For example, a system for a real-time tracking of a football match and the analysis of training [3]. The majority of technology applications in sport lie somewhere between both abovementioned groups.

According to sports experts, feedback is the most important variable for learning, except the practice itself [4]. During the practice, the natural (inherent) feedback information is provided internally through human sense organs. Augmented feedback is provided by external source, traditionally by instructors and trainers. Modern technical equipment can help both the performer and the instructor by providing additional, parallel feedback information that is not obtainable by traditional observation methods. Motor learning is essential in the process of mastering of any of the physical activities; from walking to ballet. This observation is true for any group of sportsmen or sportswoman: recreational, amateur, or professional. Technology is already present or is making its way into all domains of sport. In this paper we focus primarily on the technologies important in feedback systems for the support of accelerated motor learning.

Many sports are performed using specialized equipment. The equipment can be as simple as a baseball bat, or it can be as complex as a Formula 1 car. For complex sport equipment the technology has always played a major role in getting the competitive advantage over the opponents. For example, technologically superior bob sledge can eventually win over the technologically inferior one, even if its team is not as good. The technology is now making its way also to the simple sport equipment. Manufacturers of sport equipment have already put to market several examples of *smart sport equipment*, such as smart tennis racket, smart basketball, smart running shoes, and others [5]. While simple sport equipment might not require complex technology, it might be difficult or even impossible to design because of its size and weight restrictions, its possible violent use (golf ball), or for any other reason.

The final goal of any sport training, being recreational, amateur or professional, is in gaining an advantage. While recreational sport the aim is primarily in gaining the advantage of being fit and healthy, in amateur and professional sport the aim is primarily in gaining the competitive advantage over their opponents. Our anticipation is that the majority of recreational sportsmen and sportswomen will be satisfied with activity tracking gadgets and smartphone applications. On the other hand the competitive athletes will try to exploit any possible improvement in training process, movement execution technique, and equipment that will offer them some competitive advantage. Augmented or enhanced motor learning can play a vital role in this endeavor. The use and help of technology for this purpose can be especially important for amateurs as they rarely have a personal coach.

Our vision is to design feedback systems and applications in sport that would be able to satisfy a wide range of possible uses for augmented motor learning and that would support the use of smart sport equipment. For example, a running application would be implemented on the smartphone. It would be able to give real time feedback to the user about some basic running parameters, such left and right leg period balance and similar. Users of this application would most probably be able to improve their running technique if given some advice by an expert (coach, instructor). Another viable example is a feedback system that would give real time information about athlete's performance to the coach only. The coach would then decide if immediate feedback to the athlete is necessary or not. Such system could be also used for later more detailed analysis and terminal feedback to the athlete and/or to the coach.

According to the above said science and technology have high relevance for sport and make high impact on many sport disciplines. In this paper we limit our study to the technological and scientific influence to motor learning, which is the base for gaining a (competitive) advantage. The paper is further structured as follows. Section II describes the sport background of motor learning. Section III presents the techniques and limitations of sport signal and data acquisition and followed with Section IV that studies the means of communication for their transmission to the place of processing. Section V explains the algorithms and methods used for sport signal processing and data analysis. We conclude with section VI.

## 2. Sport background of feedback systems

Motor learning, a process of learning new movements, is essential in any sport. Motor learning is based on repetition [6]. Numerous correct executions, mostly several thousand of them, are required to adequately learn a certain movement. According to sports experts, feedback is the most important concept for learning, except the practice itself [4]. It can be concluded that motor learning heavily depends on the feedback given to the learners. In this paper we will focus on the possibilities of technology backed motor learning enhancements.

During the practice, the natural (inherent) feedback information is provided internally through human sense organs. Augmented feedback is provided by external source, traditionally by instructors and trainers, recently also by technical equipment and devices. Coach supported motor learning is depicted in Fig.1. A coach or an instructor is following or monitoring athlete's actions and gives the feedback about the performance, results, and advice about possible improvements. With this type of feedback technical equipment is not necessary as the sensors can be coach's eyes, the processing and monitoring can be done personally by the coach, the feedback to the athlete is given in any of the traditional ways: by oral advice, by drawings, by showing the correct action, etc.

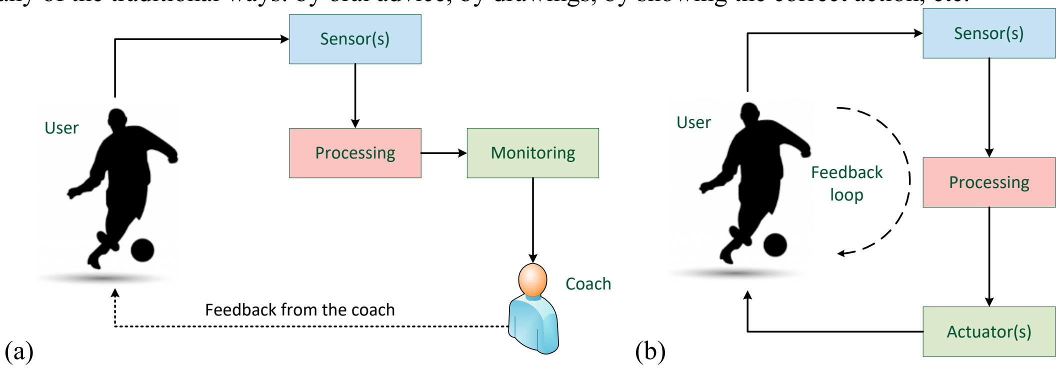


Fig. 1. (a) Augmented feedback during the traditional motor learning. A coach or an instructor is monitoring athlete's actions and gives the feedback about the performance, results, and advice about possible improvements. (b) Augmented feedback during the technology supported motor learning. A biofeedback system is monitoring athlete's actions and gives the feedback about the performance directly to the athlete.

Traditional way of coach supported motor learning can be improved by introducing technical equipment that is capable of measuring, calculating and presenting the properties of the performed action. In Fig. 1 the technical equipment is represented by sensor, processing, and monitoring block. The main reason for using technical equipment is the possibility to obtain information that is out of reach of human senses or it is beyond their capabilities. For example, a coach cannot "see" the level of force a gymnast is exerting during the jumps, or a coach cannot see the exact spot where a tennis ball hits the racket during a serve. Both, the gymnast force and the tennis ball hitting spot, can be measured, calculated, and presented by the specialized technical equipment. For example, in Fig.1 the sensor can be a high speed, high definition camera recording the tennis serve. A streamed video is processed and the ball hitting spot is calculated. The coach gets a graphical representation of the serve, accompanied by several other relevant parameters, on the tablet screen. The coach can then analyze the data and possibly give advice to the tennis player.

In the majority of research work about augmented feedback, the feedback information is given with a delay after the performed activity, which is defined as a terminal feedback. Most of the coach supported feedback can be classified as a terminal feedback. The same is true for the majority of sport applications already available on smartphones; they offer post processing with a presentation of some of the vital or important parameters. A concurrent feedback, which is given in real time within the currently performed action, has also been found useful for accelerated motor learning in recreational, professional, and amateur sport [7]. While it is not impossible for the coach to give feedback to the athlete during the performed action, such feedback has application only in specific cases. For example, the coach can give concurrent feedback to a boulder climber during the action, but a similar feedback would be of very limited value to the athlete performing a high jump.

A technology based motor learning solution with feedback is shown in Fig. 2. The solution does not include the coach and it is primarily intended for giving concurrent feedback. Such solutions are commonly described as biofeedback systems. In a biofeedback system athletes have sensors attached to their bodies for activity measuring. Sensor signals are transferred to a signal processing device, and the results are communicated back to the person (feedback) through one of the human senses (i.e., sight, hearing, touch) [8]. Athletes attempt to act on received information to change the body motion as desired. Biofeedback is successful if the user is able to either correct a movement or abandon its execution given the appropriate biofeedback information. Real-time biofeedback can reduce the frequency of improper movement executions and speed up the process of learning the proper movement pattern. Such movement learning methods are suitable for recreational, professional, and amateur users [7]-[8].

In many sports disciplines video recording and optical tracking are classical methods for providing augmented feedback information for post analysis and terminal feedback. An alternative to the above mentioned systems are wearable systems, which use one or several wearable sensors attached to the human body or integrated into the sport equipment. Wearable and integrated sensors measure the monitored quantities and they should not interfere with the activity itself. Therefore, such sensors must be lightweight and small-size and they should not physically obstruct the activity. The last requirement also implicitly defines the wireless mode of communication between the sensors, processing devices, and actuators as shown in Fig. 2.

The main question is still remaining, where are the cardinal advantages and benefits of technology backed augmented (bio)feedback? Partial answer was already given above: the technology offers possibility to obtain information that is out of reach of human senses or the information that is beyond human senses capabilities. It is not arguable that technology can outperform human senses in precision, variety of quantities measured, speed and detail of measurement, etc. It is also safe to state that technology gives objective results, while humans make subjective assessments. Maybe even more relevant question is: can science make a step into the domain of coaching? If we anticipate the move from the well-known signal processing and statistical signal analysis to the data analysis based on machine learning and data mining, we are not far from artificial intelligence (AI) in sport. With AI a vast number of possibilities open; for example, a smart eCoach that follows athlete's actions and gives advice based on all the information available from athlete's personal history and information available in the "sport cloud". Smart sport equipment is a perfect fit for such scenario.

## 3. Sport signal and data acquisition

The first step in motion analysis in sport feedback systems is signal acquisition. Motion capture systems (MCS) are an important area of research connected to feedback systems. The majority of MCS are based upon various optical systems and inertial sensors, two examples are available in [2] and [9]. Athlete's motion is captured through the measurement of various physical quantities such as acceleration, velocity, position, angular velocity, rotation angle, applied force, power, and energy. Optical MCS systems generally give spatial positions of markers; inertial sensor based MCS generally give acceleration (accelerometer), angular speed (gyroscope), and orientation in space (magnetometer). The rest of the physical quantities that are needed by the feedback system are calculated from the measured sensor quantities.

MCS can be divided into groups based on different criteria, such as place of measurement, technology, measured quantities, etc. The most common places of measurement are located on the athlete's body, on the sport equipment, and remotely. MCS are bound by many requirements. For example, sensors on the athlete's body should not obstruct the movements, sensors in or on the sport equipment should not change its properties and functionalities.

Sensor technologies, which are of great importance in MCS, have been advancing for quite a few years now. We can routinely measure quantities that were not easy to measure before; for example, accelerations and rotations of practically any body part of an athlete. Sensors measure the desired quantity or quantity that is in mathematical and/or physical relation to it. The most used are sensors based on visual technology, motion measurement technology, force and pressure measurement technology, and muscle activity measurement technology.

Visual technology includes video cameras at the low-end price ranges. At the-top end of the price range are professional MCS based on passive or active markers and high speed cameras, such as [9]. Motion measurement technology predominantly includes various MEMS (microelectromechanical systems) based sensors. The most common are accelerometers, gyroscopes, and in recent years also magnetometers. The advantage of MEMS sensors is that they are built into practically every new smartphone on the market. Force, especially in some static positions, can be measured only by sensors for pressure [10] and strain gage sensors that measure strain, which is a relative deformation of the material when exposed to acting forces. Muscle activity and muscle tension are also very important quantities that can be measured by specially developed sensors [11].

All MCS are subjected to various limitations and weaknesses. Their detailed study is not the focus of this paper. For the illustration purposes we shortly describe the properties, limitations, advantages and weaknesses of MEMS based inertial motion unit (IMU) devices, such as [12]. IMU is generally an autonomous device including one or more inertial sensors, microcontroller and often also a (wireless) communication interface. The most important properties of IMU device are: dynamic range, precision, sampling frequency, measurement errors, battery life, communication and recording capabilities, and possibility of local processing. We list only a few examples of the above properties. Dynamic range defines the range of values of the measured quantity that can be obtained by the sensor. For example, typical dynamic range of the accelerometer is $\pm 16\ g_0$. Sampling frequency defines the number of sensor quantity measurement taken in the time unit. For example, typical maximum sampling frequency of commercial IMU devices ranges from 100 Hz to 2 kHz. Battery life of IMU devices is less important, because they are easily accessible and rechargeable.

## 4. Communication

After the acquisition, the next step is getting the motion signals and data to the processing unit; and in the case of biofeedback systems also getting the feedback signals and data to the actuator. It seems that wireless communication technologies are the most obvious choice for this task, but they are not the only possibility. Sensors can be connected to a sensor node or processing device by metal wires and optical fibers or, in the case of implants, use the human body as the propagation channel [13]. Various connectivity options and wireless technologies are shown in Fig. 2. As seen, sensors or sensor devices (IMU) can be connected to the remote processing unit (laptop, smartphone, cloud) directly or over the gateway device. Gateway synchronizes sensor signals and relays them to the processing unit. Gateway can also include some local processing capabilities.

The choice of the communication channel heavily depends on the type and dynamics of the sport's activity being monitored. For example, static sports or sports with very low dynamics may allow the use of wired sensors, while high dynamic sports with a lot of movement would not. Concerning the requirement for minimum obstruction of the user the most appropriate are systems with wireless communication. Communication remains one of the urgent problems in sport feedback systems, especially in the case of concurrent biofeedback systems with real time operation.

## 5. Sport signal and data processing

Signals and data processing in sport feedback systems ranges from relatively undemanding to extremely demanding and time consuming. The processing needs on one hand and the processing capabilities on the other hand depend on a number of factors and situations: time of processing, place of processing, processing complexity, available processing power, available battery capacity, etc.

*Time of processing* depends on the type of feedback. If the feedback is concurrent, given during the action, the processing must be performed in real time. If the feedback is terminal, given after the action is completed, then the system can afford to do everything in post-processing.

*Place of processing* can be local, near-local, and remote. In the local case all of the processing is performed by the sensor device or by the gateway. Two main possible problems of local processing are available local processing power and locally available energy (battery). Local processing is performed by embedded devices; it is suitable and convenient primarily for low complexity real time biofeedback systems. Near-local processing is performed relatively close to the action. The main possible problems are the limitations of short-range communication technologies, especially in the case of concurrent biofeedback systems. Processing power can be a problem with the use of smartphones, less likely with the use of a laptop or a personal computer. Remote processing is done by any device connected to the Internet, most probably in the cloud or supercomputing center. The main possible problem is the limitation of long-range communication technologies, especially their latency.

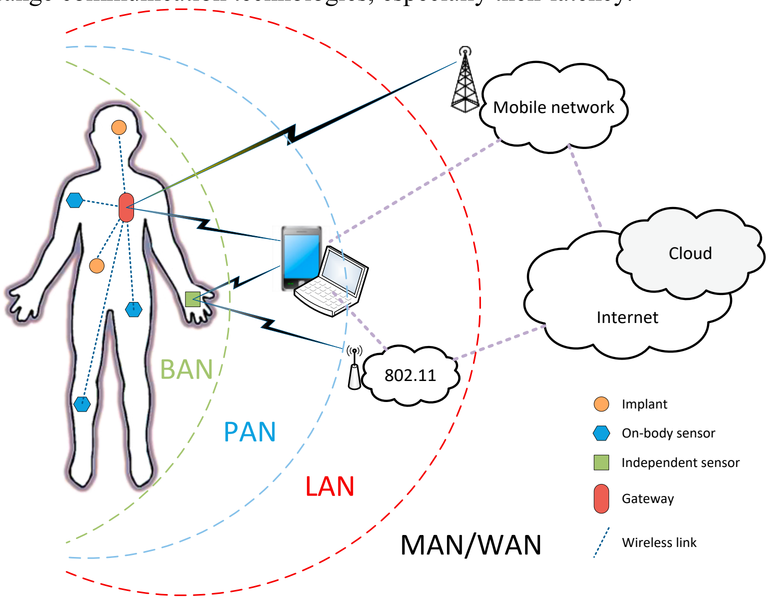


Fig. 2. Communication channels, technologies, and architectures used in sport feedback systems. Sensor devices (IMU) can be connected to the network directly or through the gateway. Processing can be done locally (gateway, IMU) or remotely (smartphone, laptop, cloud).

*Complexity of processing* depends on the amount and dimension of data, sampling frequency, algorithms, required precision, data analysis methods, etc. Processing can range from simple event counting to machine learning and data mining. Techniques and methods used depend on the intended results and timing urgency. With terminal feedback systems we can afford long processing times with complex analysis methods, but with concurrent (bio)feedback systems feedback delay is the most important factor that limits our possibilities. In concurrent biofeedback systems we cannot afford complex data analysis, we can mainly rely on signal processing algorithms and statistical methods. For example, we can trigger feedback on a pre-set signal threshold or we can track statistical measures of the current signal and trigger feedback when their deviation is too high. In terminal feedback there is much less limitation. For example, we can collect motion data for longer time periods and then apply machine learning algorithms that classify the collected movements into several groups according to the movement execution quality. One could say that in post processing only the sky is the limit.

Of course there are still a lot of challenges in the domain of signal and data processing, but their detailed study is out of the scope of this paper. Our vision is to design system that would collect motion data, learn from them based on machine learning algorithms and methods [14]-[16], and then use the acquired knowledge to perform real-time biofeedback to the athlete. Let us illustrate our vision on a golf example. Such a system would collect a number of golf swings from the golf player. In the first phase it would learn which swings are performed correctly and which are not. In the second phase the system would operate as a real time biofeedback system that would monitor each swing execution. The system would alert the player about incorrectly started swings that in great majority also end incorrectly, what results in unwanted ball flight. If the player would abort the execution of incorrectly started swing before the impact, that would result in faster motor learning and at the end also in better score in the field.

Authors in [17] have developed and implemented a real-time biofeedback system for motor learning acceleration in golf training. It measures head movements of golf players and alerts them in real time about detected incorrect and excessive head movement parameters such as rotation or translation. Tests on a group of novice golf players show that real time biofeedback speeds up the motor learning; in our case it helps to acquire the correct position and activity of the players' head. The results clearly show that real-time biofeedback is beneficial. We are convinced that with more elaborate signal processing and data analysis techniques similar results can be achieved also for more complex and more demanding motion in sport.

## 6. Conclusion

There is no doubt that athletes in amateur and professional sport will always strive for better results; according to the Coubertin's Olympic moto: "Faster, higher, stronger!" And there is also no doubt at all that science and technology can help them with it. Application of science and technology may offer significant competitive advantage, what is in today's highly competitive and commercialized sport simply priceless! The focus of this paper is accelerated motor learning with the use of technology. While it is not arguable that technology can outperform human senses in practically all aspects, one question remains; can science make a step into the domain of coaching? With a positive answer a vast number of possibilities open. For example, a smart eCoach that follows athlete's actions and gives advice based on all the information available from athlete's personal history and information available in the "sport cloud". Perhaps the world of coaching will change forever!

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## References

[1] McGrath, Michael J., and Cliodhna Ní Scanaill. "Wellness, fitness, and lifestyle sensing applications." *Sensor Technologies*, pp. 217-248. Apress, 2013.

[2] The Xsens wearable motion capture solutions, *https://www.xsens.com/products/xsens-mvn/*. Accessed: 8. September 2017.

[3] von der Grün, Thomas, Norbert Franke, Daniel Wolf, Nicolas Witt, and Andreas Eidloth. "A real-time tracking system for football match and training analysis." *Microelectronic systems*, pp. 199-212. Springer Berlin Heidelberg, 2011.

[4] Bilodeau, E. A., Bilodeau, I. M., & Alluisi, E. A. (1969). "Principles of skill acquisition". Academic Press.

[5] Lightman, Karen. "Silicon gets sporty." *IEEE Spectrum* 53, no. 3 (2016): 48-53.

[6] Giggins OM, Persson UM, Caulfield B (2013) "Biofeedback in rehabilitation." *J Neuroeng Rehabil* 10:60. doi:10.1186/1743-0003-10-60.

[7] Liebermann DG, Katz L, Hughes MD, Bartlett RM, McClements J, Franks IM (2002) "Advances in the application of information technology to sport performance." *J Sports Sci* 20:755–769.

[8] Sigrist R, Rauter G, Riener R, Wolf P (2013) "Augmented visual, auditory, haptic, and multimodal feedback in motor learning: a review." *Psychon Bull Rev* 20:21–53. doi:10.3758/s13423-012-0333-8.

[9] Motion Capture System. Available online. *http://www.qualisys.com*. Accessed 31 August 2017.

[10] FlexiForce force sensors. *https://www.tekscan.com/product-group/embedded-sensing/force-sensors*. Accessed 31 August 2017.

[11] Đorđević, Srđan, Sara Stančin, Andrej Meglič, Veljko Milutinović, and Sašo Tomažič. "Mc sensor—A novel method for measurement of muscle tension." *Sensors* 11, no. 10 (2011): 9411-9425.

[12] Shimmer3 IMU Unit. http*://www.shimmersensing.com/products/shimmer3*. Accessed 31 August 2017.

[13] Cavallari, R., Martelli, F., Rosini, R., Buratti, C., & Verdone, R. (2014). "A survey on wireless body area networks: technologies and design challenges." *IEEE Communications Surveys & Tutorials*, 16(3), 1635-1657.

[14] Lu, Di, Junqi Guo, Xi Zhou, Guoxing Zhao, and Rongfang Bie. "Self-learning Based Motion Recognition Using Sensors Embedded in a Smartphone for Mobile Healthcare." *Wireless Algorithms, Systems, and Applications: 11th International Conference, WASA 2016*, Bozeman, MT, USA, August 8-10, 2016. Proceedings, vol. 9798, p. 343. Springer, 2016.

[15] Guo, Junqi, Xi Zhou, Yunchuan Sun, Gong Ping, Guoxing Zhao, and Zhuorong Li. "Smartphone-Based Patients' activity recognition by using a self-learning scheme for medical monitoring." *Journal of medical systems* 40, no. 6 (2016): 140.

[16] Wei, Y., Jiao, L., Wang, S., Bie, R., Chen, Y., & Liu, D. (2016). "Sports motion recognition using MCMR features based on interclass symbolic distance". *International Journal of Distributed Sensor Networks*, 12(5), 7483536.

[17] Umek, Anton, Sašo Tomažič, and Anton Kos. "Wearable training system with real-time biofeedback and gesture user interface." *Personal and Ubiquitous Computing* 19, no. 7 (2015): 989-998.