A Simple Tridimensional Processing of Acceleration Measurements for Dynamic Movements Monitoring of Sportsmen

Konrad Neneman, Arkadiusz W. Łuczyk, Sławomir Szostak, and Witold A. Pleskacz

***Abstract*—Measuring, monitoring and analysis of dynamic movements in sports is becoming more important than ever. Many methods used currently may only be applied in the artificial environment of a laboratory. Other methods require too much processing to be used during a real-time competition. To overcome these difficulties acceleration measurements and a simple method to process them have been proposed. Data processing is based on search and recognition of the characteristic points in the tridimensional representation of acceleration measurements. Three different dynamic movements have been measured: run, jump and punch. The presented results show that the measurements of acceleration and proposed processing may be used to extract movement parameters of a sportsman and monitor the level of his tiredness.**

***Index Terms*—run, jump, punch, movement, tiredness, acceleration**

I. Introduction

ELECTRONIC and information systems monitoring and analyzing different movements are becoming more significant in many sports disciplines. One of their roles is to help judges to make accurate decisions during the competition. One may see it at football or volleyball matches, where ball or sportsmen movements and their position are analyzed by vision systems.

On the other hand, one can observe increasing interest in the protection of the health and condition of sportsmen, which facilitates developing sports skills and avoiding injuries [1]. An efficient and modern training program of a sportsman needs information about the quality, type and intensity of the movements performed during training or competition [2]. Their changes in time caused by tiredness, physical condition or potential injuries need to be constantly monitored.

There are many methods of measuring movement, such as: force platform [3][4], video analysis [5], interview with sportsman, and special set of exercises. All of them have a long history of usage but cannot be used during a real-time competition.

Measurements of acceleration [1] are a very good solution to this problem. This really simple method can give plenty of information about movements. It may be a very good and impartial tool for coaches or physiotherapists. In [6] the advantages of inertial sensing systems are discussed, as well as their potential applications in healthcare, sports, and well-being improvement.

However, most of todays studies on acceleration measurements are focused on motion recognition and classification. For example, in [7] the detection of walk and jog is proposed together with a classification methodology. In [8] the authors present a prototype wearable device to track arm motion using a set of inertial sensors. The obtained data were used to develop a real-time approach to motion gesture recognition. Interesting work is presented in [9] where the authors present a wearable system called Burnout, for sensing, and estimating skeletal muscle fatigue. The system relies on a network of wearable sensor nodes to detect mechanical vibrations of muscles that occur during regular exercise when a muscle is activated. The possibility of using acceleration measurements in training and improving sports skills is presented in [10]. The authors present a system to detect and classify the type of the shot with simultaneous detection of left and right footsteps. Given such information, an expert player or the trainer of an amateur player will be able to suggest improvements in the timing for each single shot type.

In this paper we present a different approach to the use of acceleration measurements. We use acceleration measurements to monitor dynamic movements, such as: jump, run and punch. Our goal is to find out whether a simple method of acceleration data analysis is enough to monitor the fatigue, physical condition and level of training of a sportsman.

In Section II we presents a brief description of the designed electronic system and the basis for our data analysis method. The measurement results with their analysis are presented in Section III. Conclusions and future works are at the end of the paper.

II. Acceleration Measurements in Dynamic Movements

Acceleration in human dynamic movements is easy to measure using relatively inexpensive MEMS sensors. For this purpose we've built a sensor module with: BMC050 3-axis accelerometer, ATMEGA8A microcontroller and M25PX32 flash memory [11]. The selected accelerometer provides many interesting features. For this design the most important ones were: configurable acceleration range, configurable sampling rate, configurable serial interfaces and low power consumption. Collecting data from the sensor, writing data to the flash memory and reading data from the flash memory was managed

K. Neneman – Alumnus of the Faculty of Electronics and Information Technology of the Warsaw University of Technology, Warsaw, Poland

A.W. Łuczyk, S. Szostak, W.A. Pleskacz are with Institute of Microelectronics and Optoelectronics, Warsaw University of Technology, ul. Koszykowa 75, 00-662 Warsaw, Poland (email: aluczyk@imio.pw.edu.pl).

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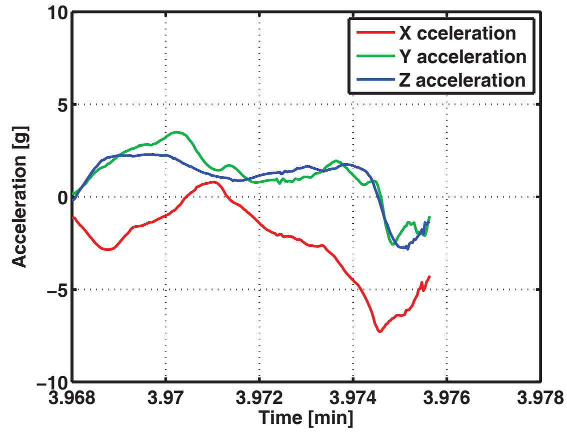

Fig. 1. Typical results of 3-axis acceleration measurement during flight phase of run

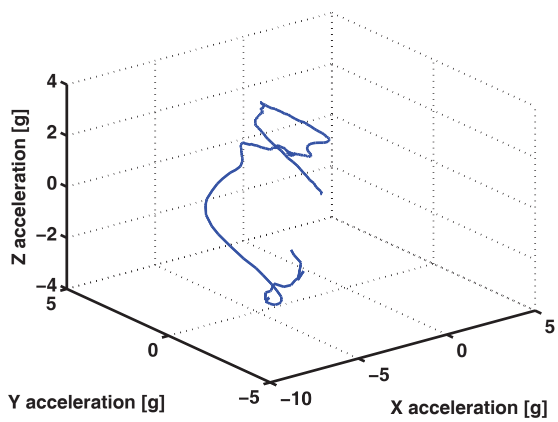

Fig. 2. Tridimensional trajectory representation of 3-axis acceleration measurements during flight phase of run

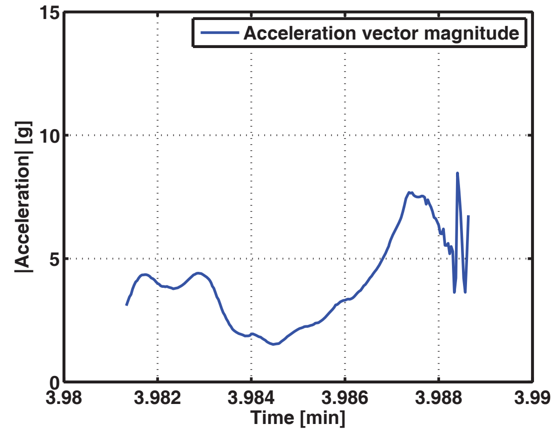

Fig. 3. Magnitude of acceleration trajectory in spherical coordinate system during flight phase of run

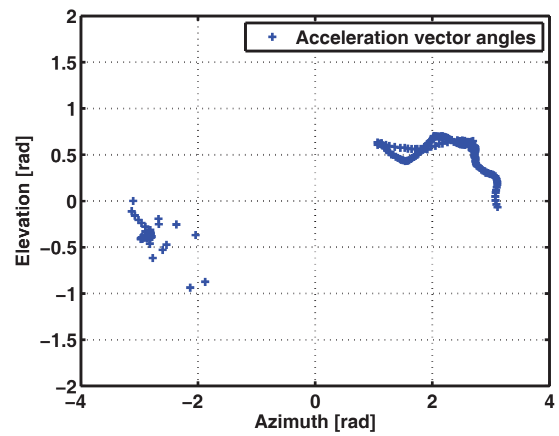

Fig. 4. Azimuth and elevation angles of acceleration trajectory in spherical coordinate system during flight phase of run

by the microcontroller. ATMEGA8A was chosen because of its simplicity in usage and reasonable power consumption. The inaccuracy of time and acceleration measurements with the designed sensor module was not higher than 5%, which was good enough for our purposes. The sensor module was attached to a human body or limb and data processing was performed off-line.

There are some important advantages of acceleration measurements, e.g.:

- do not limit human body motion,
- may be performed in open space,
- may be performed for the whole body or just limbs,
- give tridimension (3D) representation of motion.

These properties enable monitoring of sportsman movements not only in an artificial environment of a laboratory but also during the competition. Small size and weight of a sensor module do not limit or change sportsman movements. Acceleration measurements are performed individually for each sportsman and in the immediate vicinity of a body or limb motion.

Simultaneous 3-axis measurements of acceleration may be represented as a trajectory in a tridimensional space. Figure 1 shows an example of 3-axis measurements during flight phase of run and its 3D representation is shown in Figure 2. This tridimensional representation of acceleration gives interesting opportunities for movement analysis, where acceleration may be seen as the movement of a vector in 3D acceleration space. Such a vector may be represented in the spherical coordinate system with:

- magnitude (Fig. 3),
- plane of angles – azimuth/elevation (Fig. 4),

and this transformation from Cartesian to spherical coordinate system provides some interesting possibilities to analyze the acceleration during motion.

The analysis of acceleration magnitude makes it possible to circumvent the problem of the potential variation of sensor axis during motion. Furthermore, several characteristics points may be found in acceleration magnitude, such as:

- free fall $\sim 0g$,
- lack of movement $\sim 1g$,
- strike $\sim$ sudden and high change in magnitude.

These points may be used to distinguish different phases of the monitored motion. The main objective of this work was

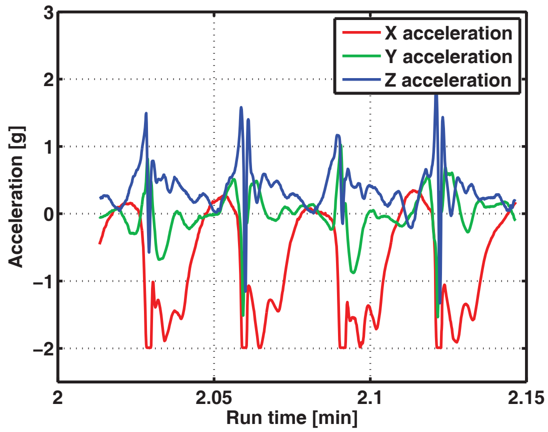

Fig. 5. Typical results of 3-axis acceleration measurement during slow run

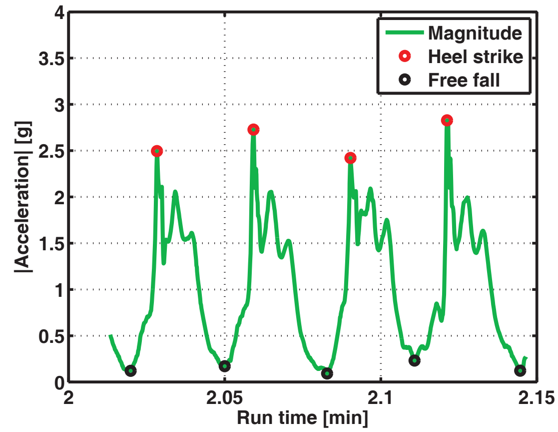

Fig. 6. Acceleration magnitude with characteristic points during slow run

to check whether a simple local search of the maximum and minimum in acceleration magnitude enables the recognition of characteristic acceleration points and measurement of the duration of different movement phases.

The plane of azimuth and elevation angles may also be used to deal with sudden motion changes during stops and hits. Such events in angle plane disrupt the continuity of a curve drawn by the acceleration vector (Fig. 4). Moreover, this plane may be used to distinguish different movements.

III. Measurements and Analysis

With our sensor module we've monitored three classes of movements: run, vertical jump and punch [1][2][4]. These movements are totally different but widely known and present in many sports. During measurements we were concentrating on temporal changes of movement parameters. We were also interested in the ability to distinguish different types of movements within a class of movement. To analyze the movements we've used a simple local search of the maximum and minimum in acceleration magnitude. This enabled us to recognize the characteristic acceleration points and measure the duration of different movement phases.

A. Slow Run

During a slow run measurement the sensor module was attached as close as possible to the center of gravity of a human body. The axes Y and Z were set in horizontal position and axis X in vertical position related to the ground. The goal of this measurement was to investigate the possibility of monitoring the symmetry of run steps.

The measurement configuration was as follows:

- run duration: 10 minutes,
- sensor module location: back/human's body centre of gravity,
- acceleration sensor range: $\pm 2g$,
- acceleration sensor resolution: 16 bits,
- sample frequency: 500 Hz.

Attaching the sensor module to the center of body mass enabled us to analyze the movements of the steps performed with either leg during run. Figure 5 shows a fragment of the obtained results representing three steps during a slow run. Figure 6 shows a fragment of the obtained acceleration magnitude with the characteristic points during run steps heel strike and free fall identified. The period between heel strikes represents the duration of step for each leg during run. It is worth to note that the acceleration magnitude has a similar shape to that obtained from classical measurements with force platform [3][4].

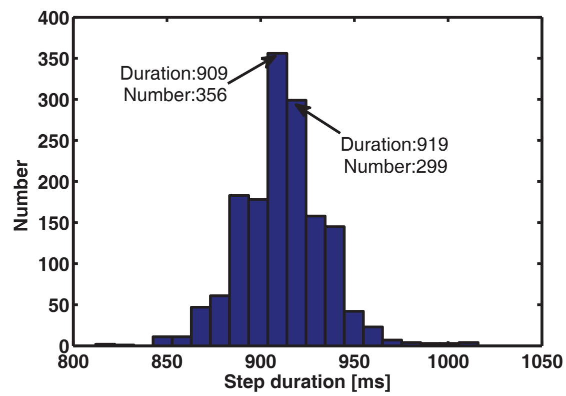

Fig. 7. Histogram of step duration during slow run

Figure 7 shows a histogram of the obtained step duration during slow run. One could expect a shape of a histogram similar to a normal distribution. Instead, histogram has a form of double bars with similar height (number) and small difference in width (step duration). The highest two bars represent 909 ms and 919 ms step duration. This slight difference and double form of bars in histogram represents the asymmetry in steps during run. Therefore, this kind of measurements may be used during training of a sportsman to improve his/her run technique or to investigate possible motion disorders and injuries during competition.

B. Run

During long-distance run the sensor was attached to the shoelaces on the right foot. The initial orientation of the acceleration sensor axis was: horizontal for X and Y axis, vertical

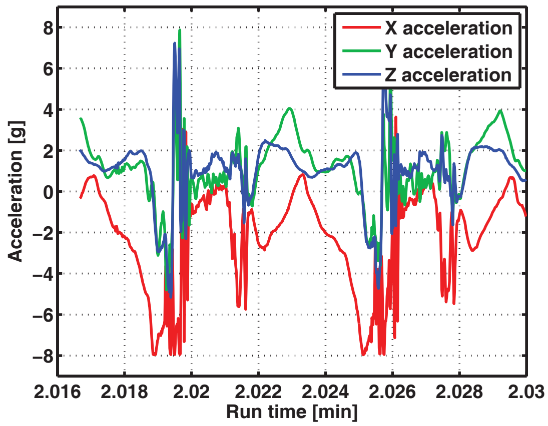

Fig. 8. Typical results of 3-axis acceleration measurement during run

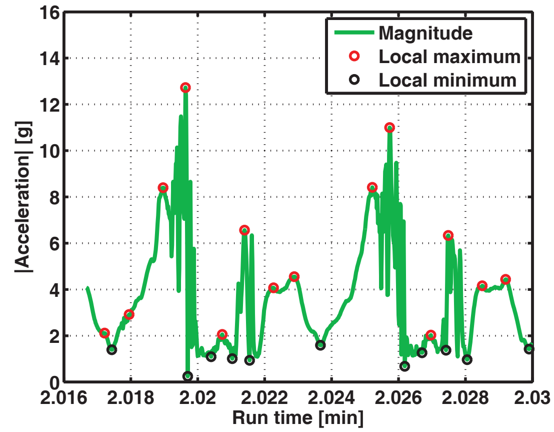

Fig. 9. Acceleration magnitude with characteristic points during slow run

for Z axis. The goal of this measurement was to investigate the possibility of monitoring the tiredness of a runner.

The measurement configuration was as follows:

- run duration: 10 minutes,
- sensor module location: foot,
- acceleration sensor range: $\pm 8g$,
- acceleration sensor resolution: 16 bits,
- sample frequency: 1000 Hz.

Attaching sensor module to a foot enabled us to analyze the duration of step phases. There are two phases during a run step: stance phase and flight phase [12]. Figure 8 shows a fragment of the acceleration measurements presenting a single step (time between 2.0195 ms and 2.0259 ms). Comparing these results to those obtained when the sensor module was attached to the body mass center (Fig. 5), one may notice more violent changes and small sharp fluctuations in acceleration. These changes are caused by the sudden changes in foot motion when the heel strikes the ground (time: 2.0195 ms, 2.0259 ms) and the foot detaches from the ground (time: 2.0215 ms, 2.0275 ms). Small fluctuations are mostly seen during the stance phase and are caused by the sensor module vibrations.

The stance phase of a run step is the period between the foot strike detachment and the flight phase is the period between the foot detachment and the next heel strike. Figure 9 shows the results of search for local minimum and maxim among the acceleration magnitude data. Although there are many points selected by such a simple approach, still the period representing the stance phase may be identified easily. This can be done by simply using the fact that during the stance phase the acceleration magnitude should be close to $1g$. Such procedure enabled us to measure the duration of run phases and the results are shown in Figure 10. One may notice that with time the stance phase is increasing and flight phase is decreasing. Also, the run step duration is increasing with time. These facts show the increasing fatigue of the runner.

C. Vertical Jump

During jumps, the sensor was attached to shoelaces on the right foot. The initial orientation of the acceleration sensor axes was: horizontal for X and Y axes; vertical for Z axis.

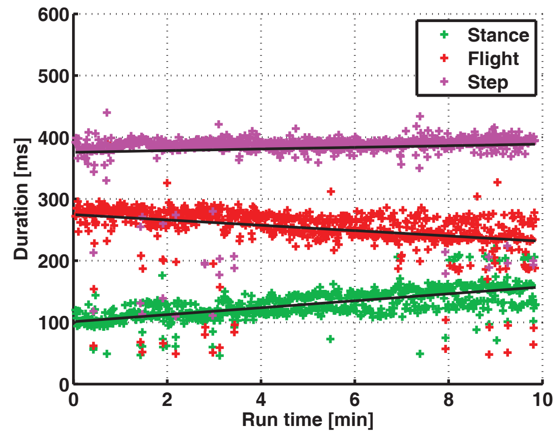

Fig. 10. Change of step, stance phase and flight phase durations during run

The measurement configuration was as follows:

- number of jumps: 30,
- sensor module location: foot,
- acceleration sensor range: $\pm 8g$,
- acceleration sensor resolution: 16 bits,

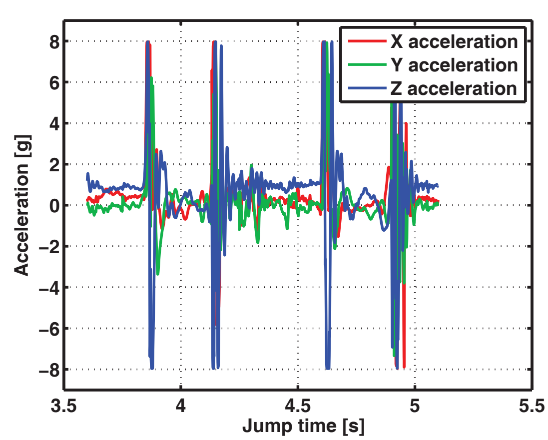

Fig. 11. Typical results of 3-axis acceleration measurement during jumps

- sample frequency: 1000 Hz.

The goal of these measurements was to investigate the possibility of monitoring a sportsmans skills and jumping technique. Therefore, acceleration was measured over a series of thirty consecutive jumps performed by three sportsmen:

- sportsman 1 – who had trained volleyball,
- sportsman 2 – who had trained water polo,
- sportsman 3 – who had a good physical condition but had never trained any particular sports discipline.

Figure 11 shows a fragment of the acceleration measurements presenting two consecutive jumps (middle of the first one is at $t = 4s$ and the second one starts from $t = 4.6s$). Just as in the case of run violent changes of acceleration caused by foot detachment from the ground and fall to the ground may be seen easily. The small sharp fluctuations in acceleration are caused by the sensor module vibration during jump time and between jumps.

Figure 12 shows the acceleration magnitude and locally selected extremes. According to the characteristic points of acceleration magnitude (Sec. II), the minima close to $0g$ value represent free fall and the minima close to $1g$ value represent lack of movement. Taking this into account one may clearly see two consecutive jumps in Figure 12 where local maxima mark the beginning and end of each jump. Therefore, the time between the maxima separated with the values close to $0g$ represent the duration of a jump and indirectly the height of a jump.

Figures 13 through 15 present the results of the extraction of jump duration from the acceleration measurements. All

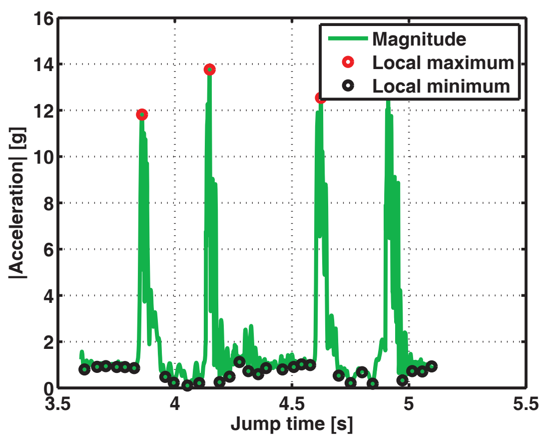

Fig. 12. Acceleration magnitude with characteristic points during jumps

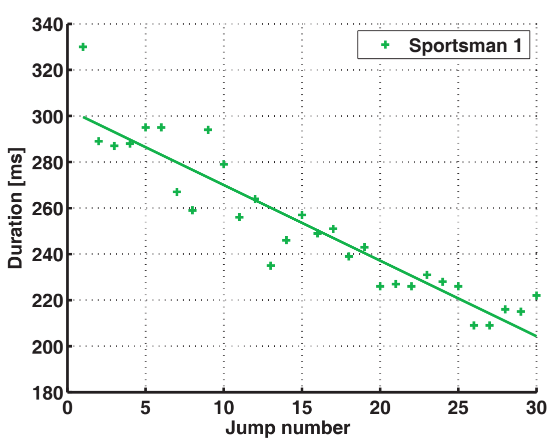

Fig. 13. Flight duration of sportsman 1 during jumps

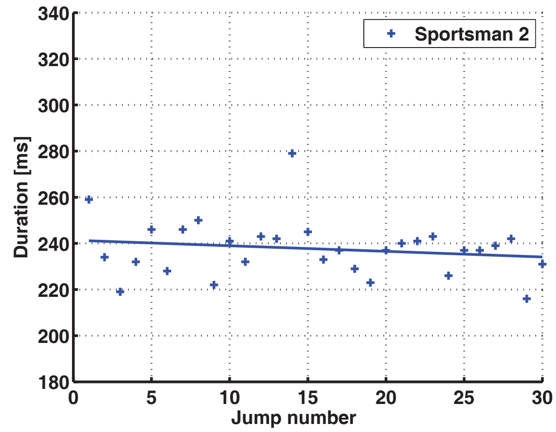

Fig. 14. Flight duration of sportsman 2 during jumps

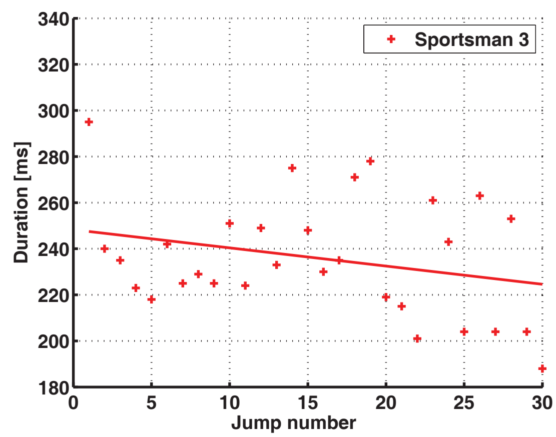

Fig. 15. Flight duration of sportsman 3 during jumps

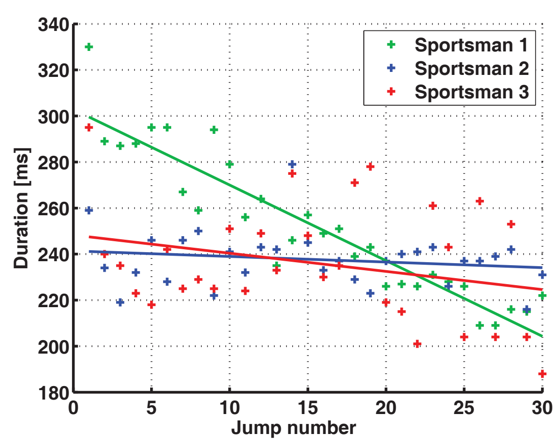

Fig. 16. Flight duration of all sportsmen during jumps

of them show a decrease in jump duration with the number of jumps. This directly indicates increased fatigue of the sportsman. One may also notice that the dispersion of jump duration for sportsman 1 is the smallest and the biggest is observed in the case of sportsman 3, although sportsman 3 may jump as high as sportsman 1. This is clearly seen in Figure 16. Sportsman 2 has for the most time of measurements the lowest height of jump. However, starting from jump 20 the linear regression of his jump duration is above the other two. The decrease in jump duration during measurements is the smallest in the case of sportsman 2. This fact indicates the physical condition of a sportsman [13].

Taking into account the sports that had been trained by the three sportsmen it may be confidently said that the acceleration measurements might be useful in assessing the quality of training and condition of a sportsman.

D. Punch

During the punch measurements the sensor module was held on hand by the performing sportsman. The initial orientation of sensors axes was: vertical for Y axis; horizontal for X and Z axes.

The measurement configuration was as follows:

- punch in the air,
- sensor module location: hand,

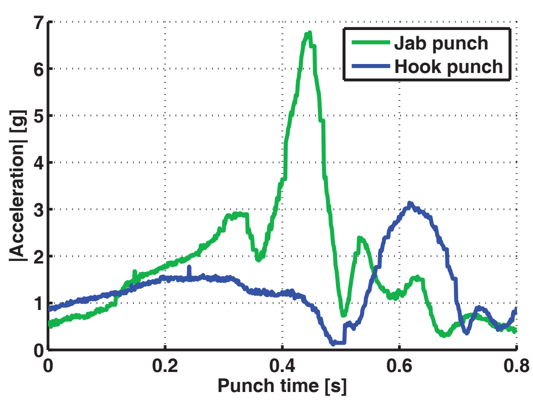

Fig. 17. Acceleration magnitude during jag and hook punches

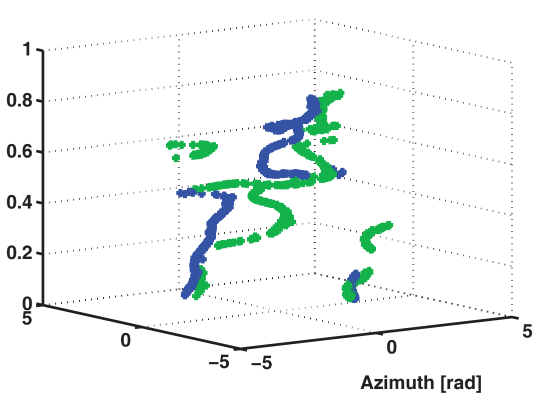

Fig. 18. Azimuth and elevation angles of acceleration during jag and hook punches

- acceleration sensor range: ±8 g,
- acceleration sensor resolution: 10 bits,
- sample frequency: 500 Hz.

We've measured two boxing punches:

- jab – a quick, straight punch thrown with the lead hand from the guard position, and
- hook – semi-circular punch thrown with the lead hand to the side of the opponent's head.

Fast movements and sudden stops might be difficult to deal with in acceleration measurements [14]. Therefore, we have decided to measure punches in the air in order to obtain accelerations below the maximum values for the acceleration sensor.

Figure 17 presents the acceleration magnitudes for jag and hook punches. One can see a fast but rather short jab punch that ends at approximately $t = 0.4s$ with a local maximum. The energy of punch is small. It is worth mentioning that the jab should be done in straight line on the horizontal plane. On the other hand the hook punch is slow but longer and often called power punch (hook ends at $t = 0.6s$). The hook is done in a semicircle line on the horizontal plane, just like jab punch. This can be seen in Figure 18. The differences between both punches are significant as seen in Figures 17 and 18. This suggests that acceleration measurements can be used to classify punches. Nevertheless, further investigations need to be made. It is worth mentioning that although local minima may be extracted, where the acceleration magnitude is close to $0g$ or $1g$, the reasoning from Section II is not applicable here.

IV. Conclusion

The electronic system for measuring acceleration and a simple method of movement parameter extraction have been presented. Measuring of acceleration in human movements may provide substantial information enabling:

- sportsman fatigue monitoring,
- monitoring of discipline-specific parameter,
- signalling and monitoring of movement disorders,
- sportsman training level evaluation.

The performed studies revealed a link between the fatigue of a sportsman and the discipline-specific parameter, such as the height of the vertical jump or duration of the stance and flight phases in run. All of them are easy to monitor with the presented approach. Additionally, the acceleration measurements can be used to distinguish different type of movements and improve training and monitoring of the physical condition of a sportsman.

The presented simple method of movement parameter extraction based on the characteristic points of acceleration magnitude may be easily implemented in a microcontroller of a sensor module. Consequently, a simple and efficient monitoring system may be built for use even during competition. The system provides important information for coach or team and facilitates decision-making. Further studies on different sports disciplines and with many sportsmen are planned.

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Konrad Neneman was born in Warsaw, Poland. He received the M.Sc. degree in electronic engineering from Warsaw University of Technology, Warsaw, Poland, in 2015. Currently employed at the GISS sp. z o.o. as a Specialist in the Research and Development team. A member of the design and research team. Professionally engaged in the design of embedded system, mainly for medical purposes, yet also experienced in the design of devices for industrial purposes.

Arkadiusz W. Łuczyk was born in Stalowa Wola, Poland. He received the M.Sc. and Ph.D. degrees in electronic engineering from Warsaw University of Technology, Warsaw, Poland, in 2004 and 2015, respectively. Since 2002, he has been with the Institute of Microelectronics and Optoelectronics (VLSI Engineering and Design Automation Division), at the same university. He is an Assistant Professor. His research interests include low-power digital and mixed signal design, processor architecture design and biomedical systems and applications.

Sławomir Szostak was born in Radom, Poland, in 1970. He received the M.Sc. and Ph.D. degrees in electronic engineering from the Institute of Microelectronics and Optoelectronics (IMiO), Faculty of Electronics and Information Technology, Warsaw University of Technology WUT, Warsaw, Poland, in 1995 and 2001, respectively. In 2000, he joined The Division of Microelectronic and Nanoelectronic Devices in IMiO. His current research interests include embedded systems, measurement systems, characterization of semiconductors materials and devices. He has designed and built several measurement systems (e.g. signal generator for charge pumping) for both laboratory and industrial applications. He was the recipient of the WUT Rectors Award for Scientific Achievements (02, 09). Since 2008 he is responsible for the cooperation of the Faculty of Electronics and Information Technology with secondary schools all over Poland. Since 2016 he is the Vice-Director of IMiO for Teaching.

Witold A. Pleskacz was born in Warsaw, Poland. He received the M.Sc. degree, the Ph.D. degree (with honors) and D.Sc. degree in electronic engineering from the Warsaw University of Technology, Poland, in 1983, 1995 and 2011 respectively. Since 1984, he has been with the Institute of Microelectronics and Optoelectronics (VLSI Engineering and Design Automation Division), at the same university. He is an Associate Professor and Head of Warsaw ASIC Design Education Center (ADEC). He spent one and half years as a Post Doctoral Researcher of Electrical and Computer Engineering at Carnegie Mellon University, Pittsburgh, PA (USA). He has authored or coauthored 6 books and over 100 papers published in conference proceedings and journals. His research interests include: methods of designing integrated circuits in submicron and nanometer CMOS technologies, computer-aided design methods and algorithms, layout-oriented manufacturing yield modeling, defect-based approaches to fault modeling, and design for manufacturability of ICs, defect oriented testing methodologies. He gave 20 invited talks and seminars in USA, Russia and 9 European countries. He has been a member of 9 international conference program committees: IEEE DFT, IEEE DDECS, IEEE YOT, CADSM, MEMSTECH, ECS, DSD-SS, ADEPT, MIXDES. Prof. Pleskacz has received various awards including: Medal of National Education Commission in 2013, Ministry of National Education Award for teaching achievements in microelectronics in 1993, Ministry of Science and Higher Education Award for education achievements in microelectronics in 2006, 5 awards for scientific and teaching achievements from Rector of Warsaw University of Technology (in 1989, 1996, 2010, 2012 and 2013), and 3 Golden Chalks Student Council of the Faculty Teaching Awards (in 2000, 2008 and 2012).