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Artificial Intelligence in Wearables - Challenges and Opportunities in Physical Therapy and Sports Training

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Abstract.
Adherence to procedures and rules is essential in order to obtain the best results in medicine and sports. However, traditional clinical setups can induce stress in patients, hindering recovery. Meanwhile, advancements in activity recognition and monitoring technology have revolutionised the sports industry, yet systems suggesting exercises for performance improvement are sparse. At the same time, children training supervision is lacking comprehensive research altogether. In my research, I propose a project that aims to unify wearables solutions in physical therapy, sport training and children development. The key aspects of the research include the exploration of sensor modality fusion in order to obtain better results, body motion tracking, and physiological parameters recording. Planned experiments will focus on joint and torso movement mapping, integration with vital signs in order to perform real-life evaluations in cooperation with athletes, patients, coaches, and therapists.

Keywords. embedded intelligence, health care, sports, human activity recognition, human computer interaction

1. Context

More and more new sensors are created and improved. It is not a surprise anymore that the wear of mechanical parts can be measured in real-time or that during a football match, we can have statistics about the condition of the players. The wide selection of types and available modalities of detectors makes it possible to do a wide range of projects that would be otherwise impossible to finish. Diverse properties such as speed, exact position, sound intensity, applied force, pressure and many more are not a mystery anymore for researchers and innovators.

There are quite a few fields in which new technology proves to be of utmost value. Medicine and sports are the ones that are widely explored as they pose significant interest to many people. The first one is an essential part of our life without which more patients would be sick and die due to many various illnesses and accidents. It is only logical that a researchers are trying to improve tools and medication used for saving lives. Sport is an elemental piece of the nature of humans. Whether it is a professional career or a late run for a bus or playing with friends, it is always present. It is not a surprise then that we want to know more about ourselves and the impact of sport on our bodies.

In medicine, new technologies and a better understanding of anatomy and physiology lead to the creation of more and more guidelines and norms. Adherence to procedures is necessary for patients' safety. There are procedures in place when surgeries are performed, when the treatment plan is created, and when patients are guided through the first steps of recovery [9,23,36,33,3,25]. In every place in all hospitals in the world, rules are strictly followed and obeyed which allows for easy routine and followings of the recovery process. However, a sterile clinic is not an optimal environment for the healing process as it puts psychological stress on patients: a necessity of being in a strange room, surrounded by strangers. It is believed that patients can heal faster at home where they can relax [8,19]. On their way out of hospital patients are usually equipped either with a physical therapy plan or a recommendation of visiting physician. Nevertheless, due to various reasons such as high costs, long distance, need to return to work or lack of necessary time, many convalescents have to resign from following recovery plan which can result in wrongly healed injuries or movement limitations [27]. Existing research has mostly concentrated on interactions with older people, sport rehabilitation, etc. [13,15].

At the same time, a great number of children start professional sports training at a young age [32,22,37,11,35]. Their training plan is created by coaches based on their work experience. However, adjusting the workload during the growth phase is crucial for the correct development of the human body [34]. Unfortunately, it is not always possible in large training groups where the coach has to take care of all the athletes. Moreover, due to great differences in children's bodies, and the way they change over time, it becomes a challenge to properly guide them in their sport career. Right now, there is hardly any research performed in the field of youth supervision, except for a few, singular works about specific sports or coping with various disabilities [38,26]. A solution that would allow for monitoring of performed exercises, predict fitness progress and recovery outcomes would help in both: rehabilitation and young athletes' training.

On the other hand, the sports industry in recent years was enhanced by recently developed activity recognition and monitoring technology. Various technological solutions were used and tested to obtain the best results in case of movement tracking: IMU sensors, camera tracking etc. [28]. However, despite a great number of producers of specialised devices, there are only singular ones that would suggest types of exercises to perform to improve one's physical form. This type of setup could be helpful for individual training and for coaches to supervise the athletes' development.

In my dissertation, I want to concentrate on closing the existing gap between an available technology, and the needs of patients and athletes for remote training supervision. The most important questions of this research that need to be explored are movement tracking in all environments, recording and analysing physiological parameters and making predictions of fitness development and recovery progress. To investigate possible designs for such tools a series of experiments will be performed. Firstly the body movement recording test will be held in a sports environment which should provide information about the optimal number and placing spots of sensors. In a similar way, the physiological parameters will be explored with additional consultations with medical doctors and physiotherapists. To answer the last question experiments combining movement and body data will be performed in cooperation with experts to ensure correct comprehension of analysed data.

1.1. Related work

Recently, one of the most popular area of sport science is movement recognition. There is a huge amount of papers that describe usage of various types of sensors in order to track and map body movements [16,4]. One of the most popular technologies is inertial measurement unit (IMU) that with use of accelerometer, gyroscope and (usually) magnetometer is able to precisely determine a position of the sensor and through that - position of tracked place [4,7,2]. However, there are a few challenges related to this technology such as existence of a drift which requires calibration phase in order to work properly. Another difficulties is the needed number of sensors for proper mapping of the body movement: to fully record the state of the joint (bending angle) two sensors are required. Despite existing issues, a lot of works obtained satisfactory results that allow for activity recognition [5,6,1,13]. Many types of sports were tested and for each one different sensors positions were used on athletes bodies as well as on used equipment [4,16]. In some of these papers researchers concentrated not only on the body tracking but also on the determining factors coming into creating a good team, proper assessment of athletes by coaches, physical strain assessment, and more.

On the other hand the capacitive sensing technology is more and more experimented with. While there are a few technical approaches to this method (sensing the body self generated electrical field or creation electrical field in an electrode and measurements of body capacitive changes) in a human activity recognition field those sensors are used with conductive textiles [6,14]. This produces systems that are easy to mount onto the human body and can be soft and easy to maintain (washing etc.) [12,31]. However, one of the disadvantage of this technology is that the gathered data can provide only information about the relative movement of body parts in relation to themselves [10,31]. This aspect makes it hard to use capacitive sensors as a stand alone solution.

Physiological data such as pulse, breathing pattern and more can be obtained in many various ways. However, taking into account that the final solution might be worn by athletes or recovering patients the bio impedance sensors were chosen. The electrodes are using low amplitude, high frequency current on the body which allows for measurements of the body impedance which is dependant on the body tissue percentage [18,29]. This parameter is utilised, among other applications, in cardiac disease examinations [17], as well as in works concerning human body tissue percentage [20], medical condition diagnosis [24], and cybersecurity authentication problems [21,30].

2. Research Idea

Presented above related papers individually are very well covering small parts of a broad field which is human activity recognition in areas of sport supervision and physical therapy assistance. Nevertheless none of those works presents a solution that would cover a few areas or could be easily transferred into another domain of interest. A system like this could be an invaluable help for people that deal daily with patients and athletes. The possibility of quick adjustment of a training or rehabilitation plan to individual needs is crucial for the success in most cases.

However creation of a solution like that poses a few questions that are pivotal to answer while development process occurs:

1. What type of data physical therapists require in order to make informed decision on recovery plans for individual patients?
2. What data coaches require in order to make informed decision on training plans for individual athletes?
3. What body parts need to be tracked for algorithm to be able to detect type of performed activity?
4. What type of body parameters (e.g. pulse, oxygenation, breathing tempo) are required additionally to tracking body movements in order to determine the training effects that performed activity has on the muscles?
5. What joints movement are required to be tracked in order to determine the whole body posture?
6. What combination of various sensors technologies is the most effective in terms of mapping specific joints movements?

To answer those questions it is necessary to performs a series of experiments. Starting from the most simple ones to determine the best fusion of sensors in attempt to get the most accurate and descriptive data. Through research focusing on gathering information about training types, decision making reasons etc. Ending with work on the final combination of previously observed data and creation a functional, easily adapted system for sport and rehabilitation purposes.

Due to the nature of described experimentation course a few challenges arise:

1. Integration of sensors data from different modalities;
2. Choosing the smallest number of sensors that would allow for accurate activity tracking;
3. Getting the sufficient number of participants from various sport backgrounds for long term study;
4. Getting the sufficient number of participants from various stages of rehabilitation for experiments;
5. Connecting all sensors together in a well working system;
6. Ensuring acceptable levels of data and system security in an Internet of Things system;
7. Creating an easy to understand and comprehend user interface for people from various background and all ages.

To overcome them it is essential to firstly, perform a throughout background research about already finished experiments and about fusion of various modality sensors; second, to begin cooperation with universities and institutions that concentrate on sport and physical therapy science; third, to ensure that the newest cyber-security procedures are in place; and fourth, perform study about user interface design including surveys in target groups of society.

3. Methodology

In order to confirm the proper work of a system each step will be tested. Experiments will be designed in small steps to ensure that nothing is missed. Ground truth for most of the experiments will be data obtained from video recordings of the experiments as it is a state of the art method in human activity tracking. The angles of the joints for first testing stages can be obtained with one of the few programs used for bio-mechanical measurements such as *Kinovea*. This part will be done in groups: first, hint joints (knee, elbow) second, ball and socket joint (hip, shoulder) third, the construct of a few types of joints (ankle, wrist), and in the end mapping of the torso. This order was designed to gradually raise the difficulty level of bio-mechanical description of the levels of freedom and movement equations. In experimentation in which it is impossible to collect sufficient video data, other methods, like motion capture with active markers, are considered. As the later phase is planned to examine strictly activity recognition in natural sport or rehabilitation environment manually created (by qualified personnel) labels will be utilised. For the last part, which is designed to be user interface, specially designed surveys will provide required feedback from testers. Classification problems will be tried with traditional machine learning methods as well as deep learning algorithms. Gathered data will be evaluated with a series of state of the art statistical parameters such as F1 score and consulted with experts in physiotherapy, and sport training fileds.

4. Future works

Each part of the research is designed as a different project to maintain order and clarity. Experiments will start with tests of joint movement mapping for ankle, knee, hip, elbows and wrists. In the next part the testing of the torso mapping will be performed. As in physical therapy and some sports the spine position is essential to the performed movement it is necessary to be able to track this part carefully. In those stages one of the priorities, apart from the accuracy of measurements, will be to minimalize number of required sensor in order to keep the cost of final system as low as possible.

After those experiments will be finished, the evaluation of a necessary physiological parameters to first determine the state of the body during performed exercises and second, to predict how it will behave in the future during similar activity.

This knowledge combined will allow to perform tests with real athletes, coaches, patients and therapist. This is a significant part of the research as it will allow fine tuning of previously created models with the aim in providing the best possible outcomes that would be useful for exactly those groups of people. In this stage it will be crucial to also create the best practices of data handling to ensure an acceptable level of security.

References

[1] Uğur Ayvaz, Hend Elmoughni, Asli Atalay, Özgür Atalay, and Gökhan Ince. Real-time human activity recognition using textile-based sensors. *Lecture Notes of the Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering, LNICST*, 330:168–183, 2020.

[2] Oliver Bodemer. Enhancing individual sports training through artificial intelligence: A comprehensive review. *Authorea Preprints*, 10 2023.

[3] M Brindle, G Nelson, DN Lobo, Olle Ljungqvist, and UO Gustafsson. Recommendations from the eras® society for standards for the development of enhanced recovery after surgery guidelines. *BJS open*, 4(1):157–163, 2020.

[4] Valentina Camomilla, Elena Bergamini, Silvia Fantozzi, and Giuseppe Vannozzi. Trends supporting the in-field use of wearable inertial sensors for sport performance evaluation: A systematic review. 2018.

[5] Haofeng Chen, Gang Ma, Peng Wang, and Xiaojie Wang. A bio-impedance analysis method based on human hand anatomy for hand gesture recognition. *IEEE Transactions on Instrumentation and Measurement*, 70, 2021.

[6] Jingyuan Cheng, Oliver Amft, Gernot Bahle, and Paul Lukowicz. Designing sensitive wearable capacitive sensors for activity recognition. *IEEE Sensors Journal*, 13:3935–3947, 2013.

[7] Swathikan Chidambaram, Yathukulan Maheswaran, Kian Patel, Viknesh Sounderajah, Daniel A. Hashimoto, Kenneth Patrick Seastedt, Alison H. McGregor, Sheraz R. Markar, and Ara Darzi. Using artificial intelligence-enhanced sensing and wearable technology in sports medicine and performance optimisation, 9 2022.

[8] Maria Crotty, Lynne C Giles, Julie Halbert, Julie Harding, and Michelle Miller. Home versus day rehabilitation: a randomised controlled trial. *Age and ageing*, 37(6):628–633, 2008.

[9] Vicki Erasmus, Thea J Daha, Hans Brug, Jan Hendrik Richardus, Myra D Behrendt, Margreet C Vos, and Ed F van Beeck. Systematic review of studies on compliance with hand hygiene guidelines in hospital care. *Infection Control & Hospital Epidemiology*, 31(3):283–294, 2010.

[10] Tobias Grosse-Puppendahl, Eugen Berlin, and Marko Borazio. Enhancing accelerometer-based activity recognition with capacitive proximity sensing. *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, 7683 LNCS:17–32, 2012.

[11] Arne Güllich and Eike Emrich. Considering long-term sustainability in the development of world class success. *European journal of sport science*, 14:S383–S397, 2014.

[12] Marian Haescher, Denys J C Matthies, Gerald Bieber, and Bodo Urban. Capwalk: A capacitive recognition of walking-based activities as a wearable assistive technology. 2015.

[13] Xu Han, Xingru Zhou, Baohua Tan, Lulu Jiao, and Ruanji Zhang. Ai-based next-generation sensors for enhanced rehabilitation monitoring and analysis. *Measurement*, 223:113758, 12 2023.

[14] Xin He, Zhihao Liu, Gengzhe Shen, Xiang He, Jionghong Liang, Yu Zhong, Tianlong Liang, Jie He, Yue Xin, Chi Zhang, Dongdong Ye, and Guofa Cai. Article microstructured capacitive sensor with broad detection range and long-term stability for human activity detection.

[15] Yanping Jiang. Combination of wearable sensors and internet of things and its application in sports rehabilitation. *Computer Communications*, 150:167–176, 2020.

[16] José Jair Alves Mendes Jr, Mário Elias Marinho Vieira, Marcelo Bissi Pires, and Sergio Luiz Stevan Jr. Sensor fusion and smart sensor in sports and biomedical applications. 2016.

[17] Sel Kaan. Science non-invasive cardiac and respiratory activity assessment from various human body locations using bioimpedance. *IEEE Open Jurnal of Engineering in Medicine and Biology*, 2:210–217, 2021.

[18] Panagiotis Kassanos. Bioimpedance sensors: A tutorial. *IEEE SENSORS JOURNAL*, 21, 2021.

[19] Raija Kuisma. A randomized, controlled comparison of home versus institutional rehabilitation of patients with hip fracture. *Clinical rehabilitation*, 16(5):553–561, 2002.

[20] Vladimir Leonov, Seulki Lee, Ana Londergan, Russel A. Martin, Walter De Raedt, and Chris Van Hoof. Bioimpedance method for human body hydration assessment. *Proceedings of the Annual International Conference of the IEEE Engineering in Medicine and Biology Society, EMBS*, pages 6036–6039, 7 2019.

[21] Ivan Martinovic, Kasper B Rasmussen, Marc Roeschlin, and Gene Tsudik. 6 pulse-response: Exploring human body impedance for biometric recognition. *ACM Trans. Priv. Secur*, 20:31, 2017.

[22] Paul J McCarthy, Marc V Jones, and David Clark-Carter. Understanding enjoyment in youth sport: A developmental perspective. *Psychology of sport and exercise*, 9(2):142–156, 2008.

[23] Yatin Mehta, Abhinav Gupta, Subhash Todi, SN Myatra, DP Samaddar, Vijaya Patil, Pradip Kumar Bhattacharya, and Suresh Ramasubban. Guidelines for prevention of hospital acquired infections. *Indian journal of critical care medicine: peer-reviewed, official publication of Indian Society of Critical Care Medicine*, 18(3):149, 2014.

[24] David Naranjo-Hernández, Javier Reina-Tosina, and Mart Min. Review article fundamentals, recent advances, and future challenges in bioimpedance devices for healthcare applications. 2019.

[25] Ravi Oodit, Bruce M Biccard, Eugenio Panieri, Adrian O Alvarez, Marianna RS Sioson, Salome Maswime, Viju Thomas, Hyla-Louise Kluyts, Carol J Peden, Hans D de Boer, et al. Guidelines for perioperative care in elective abdominal and pelvic surgery at primary and secondary hospitals in low–middle-income countries (lmic's): enhanced recovery after surgery (eras) society recommendation. *World Journal of Surgery*, 46(8):1826–1843, 2022.

[26] Stefano Di Paolo, Stefano Zaffagnini, Nicola Pizza, Alberto Grassi, Laura Bragonzoni, Academic Editors, Alberto Greco, and Alejandro Callara. Poor motor coordination elicits altered lower limb biomechanics in young football (soccer) players: Implications for injury prevention through wearable sensors. 2021.

[27] Joan D Penrod, Kenneth S Boockvar, Ann Litke, Jay Magaziner, Edward L Hannan, Ethan A Halm,

Stacey B Silberzweig, R Sean Morrison, Gretchen M Orosz, Kenneth J Koval, et al. Physical therapy and mobility 2 and 6 months after hip fracture. *Journal of the American Geriatrics Society*, 52(7):1114–1120, 2004.

[28] Franchino Porciuncula, Anna Virginia Roto, Deepak Kumar, Irene Davis, Serge Roy, J Walsh, and Louis N Awad. Wearable movement sensors for rehabilitation: A focused review of technological and clinical advances. *Innovations Influencing Physical Medicine and Rehabilitation*, 2018.

[29] Javier Ramos, José L. Ausín, Guido Torelli, and J. F. Duque-Carrillo. A wireless sensor network for fat and hydration monitoring by bioimpedance analysis. *Proceedings of the 6th International Workshop on Wearable, Micro, and Nano Technologies for Personalized Health: "Facing Future Healthcare Needs", pHealth 2009*, pages 49–52, 2009.

[30] Munehiko Sato, Rohan S Puri, Alex Olwal, Yosuke Ushigome, Lukas Franciszkiewicz, Deepak Chandra, Ivan Poupyrev, and Ramesh Raskar. Zensei: Embedded, multi-electrode bioimpedance sensing for implicit, ubiquitous user recognition. 2017.

[31] Gurashish Singh, Alexander Nelson, Ryan Robucci, Chintan Patel, and Nilanjan Banerjee. Inviz: Low-power personalized gesture recognition using wearable textile capacitive sensor arrays. *2015 IEEE International Conference on Pervasive Computing and Communications, PerCom 2015*, pages 198–206, 7 2015.

[32] Ilka Staub, Christoph Zinner, Andreas Bieder, and Tobias Vogt. Within-sport specialisation and entry age as predictors of success among age group swimmers. *European Journal of Sport Science*, 20(9):1160–1167, 2020.

[33] MC Struijk-Mulder, HB Ettema, CC Verheyen, and HR Büller. Comparing consensus guidelines on thromboprophylaxis in orthopedic surgery. *Journal of Thrombosis and Haemostasis*, 8(4):678–683, 2010.

[34] Phillip D Tomporowski, Catherine L Davis, Patricia H Miller, and Jack A Naglieri. Exercise and children's intelligence, cognition, and academic achievement. *Educational psychology review*, 20:111–131, 2008.

[35] Michael Wall and Jean Côté. Developmental activities that lead to dropout and investment in sport. *Physical education and sport pedagogy*, 12(1):77–87, 2007.

[36] Scott Weingarten, MaryS Riedinger, Meenu Sandhu, Constance Bowers, A Gray Ellrodt, Chalmers Nunn, Patricia Hobson, and Nancy Greengold. Can practice guidelines safely reduce hospital length of stay? results from a multicenter interventional study. *The American journal of medicine*, 105(1):33–40, 1998.

[37] Jean Whitehead, Natalie J Evans, and Martin J Lee. Relative importance of success in sport and school work. *Perceptual and motor skills*, 85(2):599–606, 1997.

[38] Jing Yao and Yanze Li. Youth sports special skills' training and evaluation system based on machine learning. 2022.