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Smart Office Chairs with Sensors for Detecting Sitting Positions and Sitting Habits: A Review

Pametne uredske stolice sa senzorima za otkrivanje položaja i navika sjedenja – pregled literature

REVIEW PAPER
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ABSTRACT • *The health consequences of prolonged sitting in the office and other work chairs have recently been tried to be alleviated or prevented by the application of modern technologies. Smart technologies and sensors are installed in different parts of office chairs, which enables monitoring of seating patterns and prevents positions that potentially endanger the health of users. The aim of this paper is to provide an overview of previous research in the field of the application of smart technologies and sensors built into office and other types of chairs in order to prevent diseases. The articles published in the period 2010-2020 and indexed in WoS CC, Scopus, and IEEE Xplore databases, with the keywords "smart chair" and "sensor chair" were analysed. 15 articles were processed, with their research being based on the use of different types of sensors that determine the contact pressures between the user's body and stool parts and recognise different body positions when sitting, which can prevent negative health consequences. Analysed papers prove that the use of smart technology and a better understanding of sitting, using various sensors and applications that read body pressure and determine the current body position, can act as preventive health care by detecting proper heart rate and beats per minute, the activity of individual muscle groups, proper breathing and estimates of blood oxygen levels. In the future research, it is necessary to compare different types of sensors, methods used and the results obtained in order to determine which of them are most suitable for the future development of seating furniture for work.*

KEYWORDS: *office chair; smart chair; sensors; smart seating; internet of things; health*

SAŽETAK • *Posljedice dugotrajnog sjedenja na uredskim i drugim radnim stolicama u posljednje se vrijeme pokušavaju ublažiti ili spriječiti primjenom suvremenih tehnologija. U različite dijelove uredskih stolica ugrađuju se pametne tehnologije i senzori, što omogućuje praćenje rasporeda sjedenja i izbjegavanje položaja koji potencijalno ugrožavaju zdravlje korisnika. Cilj ovog rada jest davanje pregleda dosadašnjih istraživanja u području primjene suvremenih pametnih tehnologija i senzora ugrađenih u uredske i ostale vrste stolica radi prevencije obolijevanja korisnika. Analizirani su članci objavljeni u razdoblju od 2010. do 2020. i indeksirani su u bazama podataka WoS CC, Scopus i IEEE Xplore, a izdvojeni su prema ključnim riječima pametna stolica i senzorska stoli-*

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ca. Obrađeno je 15 članaka u kojima su se istraživanja temeljila na primjeni različitih vrsta senzora koji određuju kontaktne tlakove između korisnikova tijela i dijelova stolice te raspoznaju različite položaje tijela pri sjedenju, čime se mogu prevenirati negativne posljedice za zdravlje. U analiziranim istraživanjima autori su dokazali da primjena pametne tehnologije i bolje razumijevanje sjedenja uporabom različitih senzora i aplikacija kojima se očitava pritisak tijela i određuje njegov trenutačni položaj može preventivno djelovati zahvaljujući praćenju rada srca i broja otkucaja u minuti, aktivnosti pojedinih mišićnih skupina, pravilnog disanja, procjene razine kisika u krvi i sl. U budućim istraživanjima potrebno je usporediti različite tipove senzora, primijenjene metode i dobivene rezultate kako bi se uočilo koji su od njih najprikladniji za budući razvoj radnog namještaja za sjedenje.

KLJUČNE RIJEČI: *uredska stolica; pametna stolica; senzori; pametno sjedenje; internet stvari; zdravlje*

1 INTRODUCTION
1. UVOD

Sitting in office and other work chairs has become an almost unavoidable body position in today's work environment. However, as much as sitting offers comfort unlike many physically strenuous body positions, prolonged sitting at work has consequences for the human body and leads to back pain, musculoskeletal deformities, headaches, swelling of the lower extremities and similar phenomena. The reason for these phenomena is in sitting positions, which are an unconscious act folr the majority of the working population, which includes pupils, students, office workers, in short, all age groups who sit and work at the desk.

Because of numerous health problems, mostly in office workers, recent research deals with the application and installation of smart technology and modern sensors in work chairs and other types of seats in order to analyse and monitor data using supporting applications, aiming to promote user health.

One of the well-known networks that provides the use of smart sensors is the more ubiquitous Internet of Things (IoT) – which has already entered our daily lives and is used in various areas of our life habits. Griffiths and Ooi (2018) quoted Gartner's definition of IoT as "the network of physical objects that contains embedded technology to communicate and sense or interact with their internal states or the external environment", whose possibilities are endless. In their work, they stated that "mass digitalisation and IoT will transform many industries". The furniture industry is no exception. Every day more and more types of furniture accept and implement modern technology, increasing its functionality and usability. Moreover, the furniture gets some new features and provides the user with new possibilities.

It is well known that prolonged passive sitting is not healthy, and body position should be changed frequently during sitting. In modern times, intensive digitalisation and computerisation of work requires longer sitting during working hours and life in general. It is interesting that we as humans have existed for approximately 200,000 years, but we have been sitting much more often only for the last 200 years (Harari, 2015). Sitting has become an unavoidable daily habit, and the chair becomes an "icon" in our environment wherever we are. This means that our body has had plenty of time to biomechanically adapt to walking and active living, and only 200 years to living in a predominantly sitting position. Such a relatively sudden change certainly contributes to the occurrence of pain in the human body caused by irregular and excessive sitting.

Excessive and irregular sitting is the subject of many studies as a potential cause of various (especially spine) diseases (Liebenson, 2002; Vergara and Page, 2002; Gallagher, 2005; Scena and Steindler, 2008; Hartvigsen *et al.,* 2018). The way people sit is not likely to cause pain at the end of the day, but daily prolonged sitting will create a physical problem and body aches. The way of life of modern man in industrialised and economically developed countries has brought the human body into an unenviable physical state, and deformations and musculoskeletal disorders (MSD) are increasing. MSD such as neck and low back pain, but also muscular pain in arms and legs are by far the most common, and have been widely reported as being of significant health and economic concern in industrialised countries (Grimes and Legg, 2004; Lima and Coelho, 2011; Besharati *et al.,* 2020). Because of the above problems, people want to sit healthier. According to Ahn *et al.* (2015), the health care paradigm has changed from the former medical diagnostic service and treatment to today's health service dealing with continuous health management and prevention. Sitting at office is especially emphasised because on an average 8-hour workday employees are expected to work diligently and spent more time sitting in a chair. Since their frequent and intensive use during office work is assumed, office chairs are a suitable medium for this type of research and the most common objects in/on which various sensors are installed (Vlaović *et al.,* 2007; Goossens *et al.,* 2012; Zemp *et al.,* 2016).

The literature describing the use of different sensors and technologies that detect the way we sit, how long we sit and what impact it has on our health has been studied. There are a number of different methods and sensors for reading pressures and obtaining data during and about sitting (Jürgens, 1997; De Looze *et* *al.,* 2001; Kuijt-Evers and Van Dien, 2003; Aissaoui *et al.,* 2001; Ragan *et al.,* 2002; Gyi and Porter, 1999; Davies *et al.,* 2000; Vlaović *et al.,* 2012). However, the question is how to interpret such data and how to process them so as to use them for the purpose of preventing diseases caused by prolonged, irregular and uncomfortable sitting on the chairs, which can often be unsuitable for work, improperly adjusted for sitting and with other defects. Another, no less important problem is the position and location of the installation of sensors that can significantly affect user behaviour and comfort (Bibbo *et al.,* 2018).

1.1 Sitting as a cause of disease in office jobs

1.1. Sjedenje kao uzrok obolijevanja tijekom obavljanja uredskih poslova

Office work plays a significant role in the health of modern employee, especially since today's jobs are based on the use of information technology, robotics and long-term sitting. Unfortunately, in addition to the positive consequences of the introduction of digitalisation, there are more and more negative consequences for the health of the office workers.

Wahlström (2005) quoted many authors who believed that musculoskeletal symptoms of visual display units (VDU) users have a multifactorial aetiology: non-neutral wrist, arm and neck postures, the work station design and the duration of VDU work; psychological and social factors, such as time pressure and high-perceived workload, are believed to interact in the development of these symptoms. Several other studies (quoted in Parvez *et al.*, 2019) pointed out seat-related MSDs between prolonged sitting and back pain, and many analyses even suggested that sitting and satisfaction with furniture were linked to some MSDs symptoms. For employees who work with computers and on physically inactive jobs, prolonged sitting at work becomes a major body posture. Data from the Netherlands and Australia indicate that employed adults can spend up to half of their working day sitting, while in the U.S., time-use surveys have shown that people in full-time employment spend an average of 9.2 hours working on weekdays, much of which will involve sitting. A study of sitting habits of Australian workers found that persons who work full-time sit for an average of 4.2 hours per day at work, and the remaining 2.9 hours are spent in their free time sitting (Van Uffelen *et al.,* 2010). Another study (Ertel *et al.,* 1997) shows that the average office worker spends about 50,000 hours seated during his working life, in typical office workplace such as a computer workstation. About 40 % of office workers develop problems with back pain and deformities that result from a lack of physical activity when working with a computer.

Eurobarometer's survey (quoted in Schwartz, 2016) showed that 11 % of all Europeans over the age of 14 sit for more than 8.5 hours a day. Unfortunately, the nowadays situation caused by the COVID-19 pandemic and restrictions increased this problem on a global scale (Amelot *et al*., 2021).

To avoid, or at least to reduce pains and deformations, sport engagements or physical activities for at least 30 minutes a day are recommended. Owen (2009) finds that a large number of sedentary activities on a daily basis, regardless of the amount of physical activity, is associated with the development of chronic spinal diseases or so-called MSD/LBPs. Referring to several authors, Bontrup *et al.* (2019) state that lower back pain (LBP) is the third leading cause of absenteeism due to self-diagnosed inability to work without pain at work, and that sitting for periods longer than seven hours a day significantly contributes to the risk of lower back disease. On the other hand, the same authors refer to several articles that have failed to confirm the association of excessive sitting while working in the office with the risks of lower back disease, mainly due to the deceptive nature of lower back pain, possible data processing error or unreliable measuring devices, short measurement time and potentially insufficient number of respondents.

Schoberth (1962) (quoted in Harrison *et al.,* 1999) defined three different sitting postures on the basis of the proportion of body weight transmitted to the floor by the feet and the location of the centre of grav-

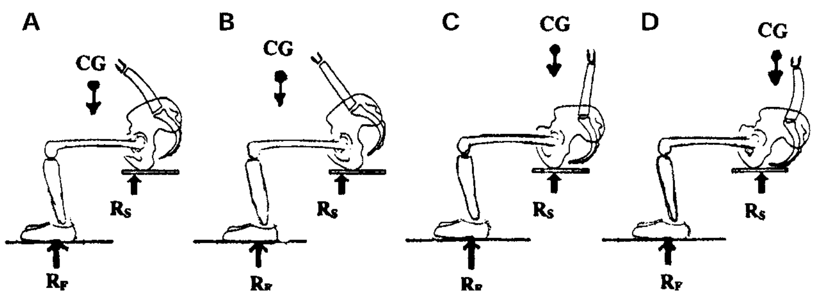


Figure 1 Sitting categories based on centre of gravity (Schoberth (1962) cited in Harrison *et al.,* 1999) RS – reaction force through seat bottom, RF – reaction force from ground to feet, CG – centre of gravity of body mass above pelvis
Slika 1. Kategorije sjedenja s obzirom na težište tijela (Schoberth, 1962.; citirano u: Harrison *et al.,* 1999.)
RS – sila reakcije kroz sjedalo, RF – sila reakcije poda na stopala, CG – težište mase tijela iznad zdjelice

ity of the body. These sitting postures (Figure 1) were termed as: anterior (A and B), middle (C), and posterior (D). Schoberth noted that these three postures also differed with respect to the shape of the lumbar spine. Later works based on this principle (Ribeiro *et al.,* 2015; Ishaku *et al.,* 2019; Mizumoto *et al.,* 2020) aimed at monitoring and recognising sitting position.

A major cause of the disease due to improper sitting could be the fact that different types of office chairs, produced by different producers, have different adjustable parameters and solutions that mostly confuse the users. Users often do not use all of the adjustments, and thus do not use the office chair in the optimal ergonomic way (Goossens *et al.,* 2012). The next problem connected to disease due to improper sitting could be incompatibility of seating furniture dimensions and user's anthropometry, and this starts quite early in school time (Dowell, 1995; Gouvali and Boudolos, 2006; Asif *et al.,* 2012; Adu *et al.,* 2014; Iliev *et al.,* 2019).

Prolonged sitting is also recognised as a serious metabolic health problem due to several pathogenic mechanisms that link muscle inactivity with increased health risks due to low energy consumption, leading to fat accumulation, and may lead to mild inflammation, decreased endocrine function of the glands which can cause poor work of several organs and tissues accompanied by decreased secretion of antioxidants (Grooten *et al.,* 2013).

1.2 Aim of paper
1.2. Cilj rada

The aim of this paper is to present the state-of-the-art techniques and sensors technology applied when sitting in office chairs and other types of chairs, in order to prevent certain diseases and increase the health of users.

In order to monitor our own sitting behaviour and determine how our sitting positions affect our health, research on sitting in chairs with various types of sensors has been conducted in recent times. In addition to understanding our body postures while sitting and permitting to monitor the body postures for a certain period of time, these sensors have the purpose of preventing body deformities and body positions that affect pain, and encourage us to sit more comfortably and appropriately to our body and to improve the quality of sitting and consequently the quality of our lives.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Method of selecting relevant literature
2.1. Metoda odabira relevantne literature

The paper presents the review obtained by searching open source articles published from 2010 to 2020 and indexed in the Web of Science Core Collection (WoS CC), Scopus and IEEE Xplore databases,

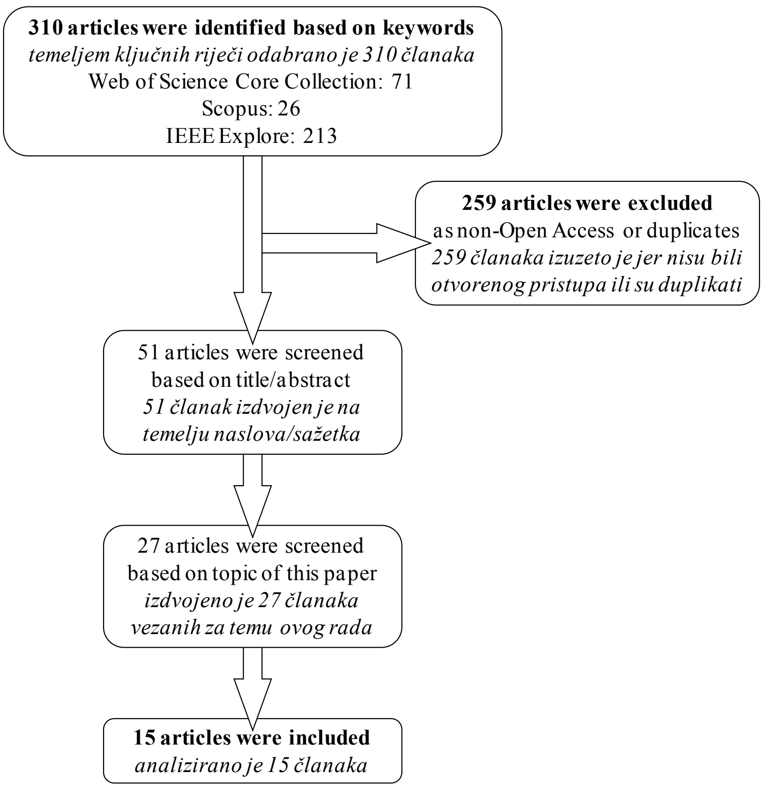


Figure 2 A schematic structure of article selection
Slika 2. Shematski prikaz probira članaka

which were found by March 18, 2020. Keywords were "smart chair" and "sensor chair".

After selecting a large number of "raw" articles, the narrower favourable criteria related to the topic of this paper were applied, such as: sensors integrated in the seat or other parts of the chair; use of sensors that detect sitting position and sitting habits; and systems that give the chair the adjective "smart chair".

Searching of open-source articles by keywords in all three databases resulted in 51 papers. After reviewing the papers and assessing the similarities with the research topic, 15 papers remained (Figure 2).

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

Further selection and presentation of articles was based on the type of sensor (pressure, tension, capacitive, heart rate), the mode of operation of the sensor (contact, contactless, wireless), the method of processing the collected data and the existence of the application software for the user.

Lee *et al.* (2019) developed a smart chair that can detect and classify some common daily activities of elderly people. The proposed smart chair is built from simple and sophisticated devices yet robust enough to detect five activities of individuals in sedentary positions. These activities include eating, working at the desk, watching TV, napping, and coughing. The smart chair is composed of six pressure sensors, an analogue-to-digital converter, mini-computer, and a conventional office chair. Four pressure sensors are placed on the seat to collect data while the subject is sitting upright and two on the backrest to collect information when the subject leans back. These sensors generate analogue signals, and the A/D converter is used to convert the collected signals to digital signals for the mini-computer, which transmits the digital signals to a server for pre-processing and analysis (Figure 3).

For the purpose of their research, three different machine learning algorithms were employed. These algorithms were the random forest (RF), extremely randomised trees (ERTs), and support vector machine (SVM). Two phases of experiments were conducted on the collected data upon submission to the server, namely, user-dependent and user-independent experiments. The RF and ERT classifiers demonstrated a very high classification performance during the experiments, the highest being attained by ERT. ERT obtained up to 98 % in the user-dependent phase and 97 % in user-independent phase. According to authors, the results obtained by the classifiers on the five activities showed that the proposed algorithm outperformed all the others mentioned in the literature. The chair has the potential to be a huge source of information on the behaviour of people since most indoor activities are performed in sedentary positions.

A cushion-based system to assess activity levels and recognise the activity from the information hidden in sitting postures of sedentary lifestyle population was developed by Ma *et al.* (2017). It is suitable for monitoring the sitting behaviour in contexts such as workplace, car, or on wheelchairs and can be easily implemented with low-cost embedded devices. Authors use the smart cushion on the chair, equipped with the effective combination of pressure and inertial sensors for non-invasive monitoring of users' postures and body swings (Figure 4). Also, they constructed a body posture analysis model to recognise sitting behaviours and a method to assess the activity levels based on the evaluation of the activity assessment index. An activity can be recognised and activity levels can be quantified so as to provide users with reminders to exercise or take a break and therefore to minimise the health risk as well as to give the users timely necessary interventions.

The results showed that, using the newly designed smart cushion and the standard deviation features, the present system is able to achieve the accuracy higher than 89 % for activity recognition and higher than 98 % for activity level recognition.

Zazula *et al.* (2015) presented a smart chair with unobtrusive sensors that measure functional health pa-

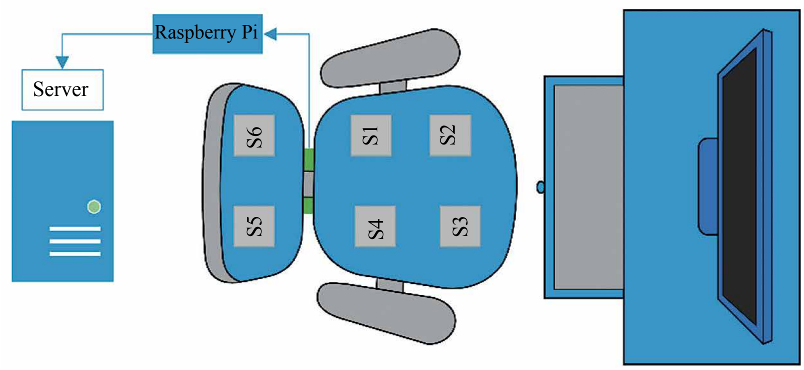
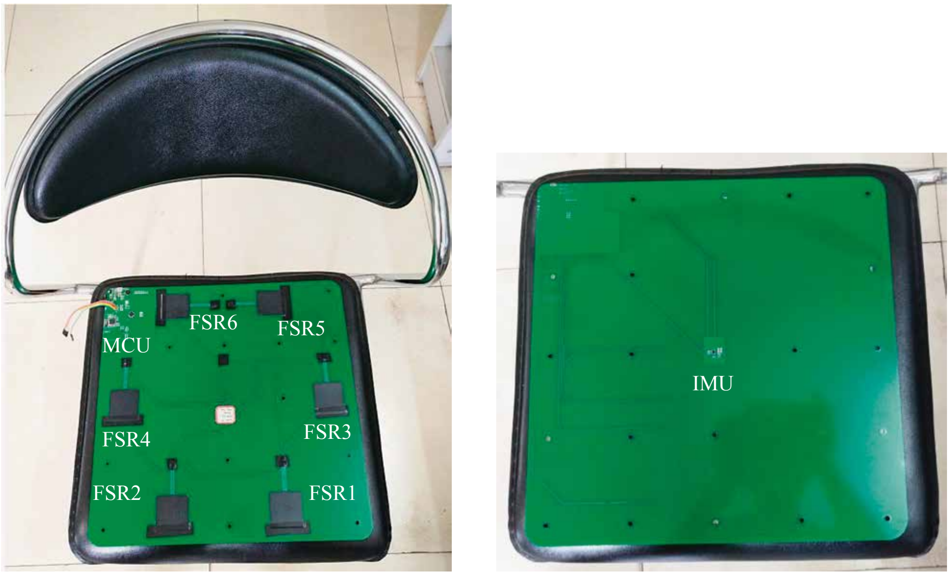


Figure 3 System architecture of smart chair for activity recognition (Lee *et al.*, 2019)
Slika 3. Arhitektura sustava pametne stolice za prepoznavanje aktivnosti (Lee *et al.*, 2019.)



a) Circuit board – front side/ *Prednja strana* b) Circuit board – back side / *Stražnja strana*

Figure 4 Smart cushion circuit board on a chair (Ma *et al*., 2017)
Slika 4. Tiskana pločica pametnog jastuka na stolici (Ma *et al*., 2017.)

rameters of a person sitting on the chair. Although capacitive sensors are placed in the chair's backrest and seat, authors were focused on measurements made by a combined sensory device in the chair armrests. It captures photoplethysmographic (PPG) and electrocardiographic (ECG) signals in parallel, which enables the assessment of various cardiovascular parameters (Figure 5).

Experiments described in respective paper analyse parallel recordings of the PPG and ECG signals only. All acquired measurements were synchronised by a microcontroller build in the chair and wirelessly transmitted to a host computer. Analysis algorithms extracted relevant features and estimated parameters of functional health, and rendered those data by user interface adapted to run on mobile devices. Authors modelled the relationship between pulse transit times and subject's blood pressure by linear model in four situations, i.e. for systolic and diastolic referential pressures at rest and after the exercise. Results show that agreement between the references and modelled estimates is not accurate enough for systolic pressures, but is acceptable for diastolic pressures. Relationship between referential blood pressures and estimated pulse transit times unveiled inferior fitting of systolic blood pressures, both at rest and after exercise and, according to authors, a possible reason might be individ-

a) Unobtrusive sensors in backrest, seat, and armrests / *Nenametljivi senzori u naslonu, sjedalu i naslonima za ruke*

b) U-shaped ECG electrode under armrest / *EKG elektroda U-oblika ispod naslona za ruke*

Figure 5 Gaming chair modified for experiment (Zazula *et al*., 2015)
Slika 5. Stolica za igrače računalnih igara prilagođena pokusu (Zazula *et al*., 2015.)

ual differences in vascular parameters that influence this relationship.

An ergonomic chair with embedded IoT technology using support vector machine (SVM, a supervised machine learning algorithm that can be used for both classification and regression challenges) is presented in the work of Prueksanusak *et al.* (2019). The research proposes smart IoT chair that can classify sitting posture by means of artificial intelligent techniques. In the present paper, traditional machine learning techniques were applied to find the best sitting posture classification model. Five algorithms were selected: SVM, Bernoulli, Gaussian, MLP (multi-layer perceptron) Classifier and Logistic Regression, and conducted in terms of comparison of system performance. On hardware side, there were six force sensors set under the chair surface and four force sensors at the chair backrest. Collected data were sent to the server for predicting five sitting postures, such as: straight, sitting with left leg crossed, sitting with right leg crossed, only sitting on half chair and leaning against a chair. Results showed that all machine learning techniques achieved the accuracy over 90 %, while SVM achieved the highest accuracy in the setting environment with 96.2 %. Therefore, the authors chose this algorithm to develop a model for predicting sitting position in a mobile application, with the aim to reduce the incidence of office syndrome promoting the user to have a proper understanding of seating and recognising the problem of office syndrome in sitting posture. The user can monitor the results of predictions via mobile application in real-time, and in case the user has wrong sitting posture, he or she will be warned about it.

Research of Kumar *et al.* (2016) brings results of sedentary activities and behaviour assessment with smart sensing on chair backrest. Authors designed a smart chair system named *Care-Chair*, which can non-intrusively detect and analyse chair occupant's daily sedentary activities and behaviour. The system uses only four force sensitive resistor type sensors on the chair backrest to recognise and classify very fine-grained and complex activities while sitting. Additionally, the *Care-Chair* system is designed to estimate user's breathing rate during relatively static activities (Figure 6).

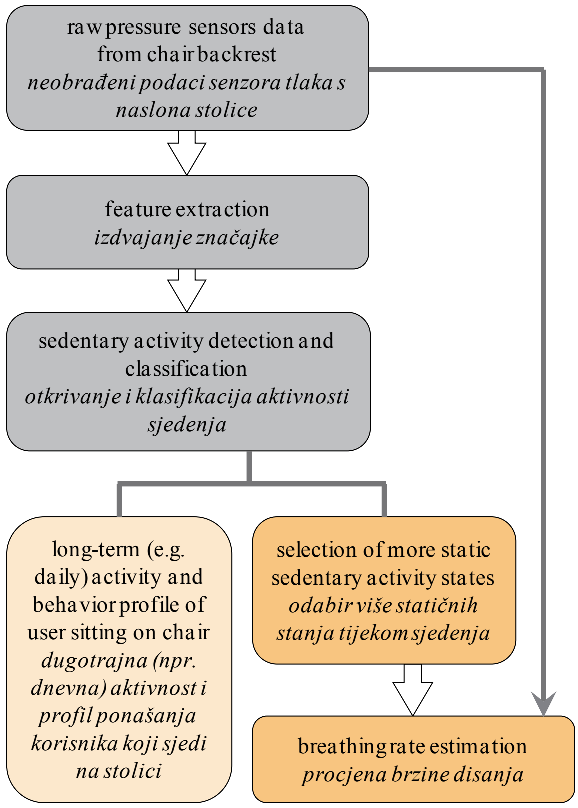
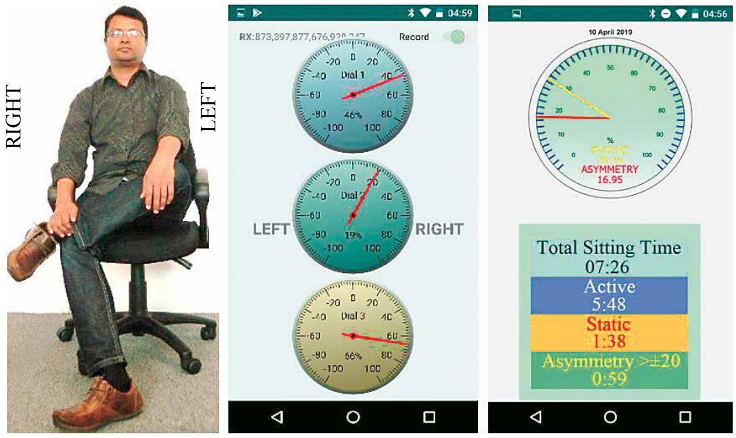


Figure 6 Flowchart of overall functionality of Care-Chair product (Kumar *et al.*, 2016)
Slika 6. Dijagram toka ukupne funkcionalnosti proizvoda Care-Chair (Kumar *et al.*, 2016.)

Interesting findings are that the sensors placed on chair backrest are more sensitive to various functional and emotional activities in sedentary position, as compared to the sensors on the seat. Namely, according to authors, the key difference between the present paper and other relevant studies is that their interest is focused on functional and emotional activity contexts rather than only on static/movement postures. Thirteen machine learning classifiers were used for comparing their accuracy performance and training delay: Linear Discriminant Analysis (LDA), Quadratic Discriminant Analysis (QDA), Stochastic Gradient Descent (SGD), Support Vector Machine (SVM), K-Nearest Neighbors (kNN), Gaussian Naive Bayes (GNB), Multinomial Naive Bayes (MNB), Bernoulli Naive Bayes (BNB), Decision Tree (DT), Random Forest (RF), Extremely Randomised Trees (ERT), AdaBoost (AB), and Gradient Boosting Trees (GBT); finally ERT classifier was chosen for further analysis due to high accuracy and low delay in training phase. The *Care-Chair* system is validated to be able to classify a large number of 19 fine grained and complex user sedentary activities including user functional and emotion-based activities, not only the static and movement based sedentary activities and postures. The system is also validated to estimate user's breathing rate with high accuracy performance.

Anwary *et al.* (2019) dealt with the real time visualisation of asymmetrical sitting posture (ASP), which undoubtedly affects the body mechanics and puts various body segments under strain. That strain may lead to health problems such as musculoskeletal and low back pain, spinal deformity, etc. Therefore, authors developed an automatic real time asymmetric sitting posture monitoring system based on a multi-layered architecture of flexible pressure sensors compatible with human biomechanics, which could be embedded in complex interfac-



a) b) c)

Figure 7 Example of asymmetrical sitting posture in experiment (a) and mobile application monitoring interfaces (b, c) (Anwary *et al*., 2019)
Slika 7. Primjer asimetričnog položaja sjedenja u pokusu (a); sučelja za praćenje mobilnih aplikacija (b, c) (Anwary *et al*., 2019.)

es, such as seat cover or chair and mobile application for real time data visualisation. Figure 7 shows the asymmetrical sitting posture with cross-leg position (a), dial based asymmetrical sitting posture visualisation (b) and a sitting score with a day summary (c).

According to authors, during a sitting posture, the pressure distribution of both right and left side should theoretically give identical results and therefore perfect asymmetry should give dial indicator readings of zero. The dials (Figure 7b) display asymmetry for thigh, buttock and shoulder regions, where it can be seen that there is a difference in the level of asymmetry. Positive value readings indicate that the pressure distribution of the right region is higher than the left, while a negative value indicates the pressure of the left region is higher than the right region. A high reading indicates higher asymmetry and a reading around zero value indicates good sitting posture. The app records daily reading and estimates the duration of total sitting, active, static and asymmetry sittings (Figure 7c). The present system differs from the existing ones in the meaning of integrating posture visualisation in real time with post analysis of collected data, which provides an easy, user friendly, private and secure way to visualise and monitor the sitting posture. According to the authors, the system can be used for monitoring and rehabilitation of diseases associated with sitting posture in different clinical setting, work place, school and patient's home.

The smart chair cover for posture correction (Kim and Lim, 2019) recognises the postures through the pressure sensor, informs the user of the real-time posture, and precisely distinguishes the correct posture from the incorrect by deep learning. The smart cushion system uses two pairs of 30 pressure sensors embedded in flexible pad (one on the seat, the other on the backrest) and connected to Arduino module. The data was transmitted to the smart device via wireless communication, and from this data, the posture was identified by the system. The identified posture was then compared to the value previously stored in the database. The image and text apt for the posture defined were transmitted to the smartphone and informed the user about his correct or incorrect sitting posture. Despite the fact that only 10 participants were involved in the experiment, authors demonstrated this idea using deep learning system to augment data from a small number of participants and confirmed the effectiveness of the developed system. Moreover, they are convinced that the suggested system can tell the exact posture of the users and that the users can correct the posture by themselves, which will be further bolstered by future research with various and expanded experimental groups.

Sifuentes *et al.* (2019) developed a measurement system to detect and confirm the presence of a subject (or object) on a chair. They propose a novel measurement method for detecting and classifying seat occupancy using a single force sensitive resistor (FSR). The proposed system first detects the subject by monitoring his/her weight and then confirms his/her presence by monitoring the respiration.

For the subject/object classification, additional information is usually required, and in this case, it was extracted from the FSR itself, which is also used to monitor the respiratory signal (Figure 8). The occupancy was expected to cause a large-signal variation of the FSR, whereas the respiration generates a small-signal variation enabling the confirmation of the presence of a human rather than an object. It should be noted that the same FSR sensor was used to wake the microcontroller unit in the presence of the subject/object and then to monitor the respiratory signal to confirm the presence of the subject. It should be mentioned that the system functions without using any intermediate analogue electronics, thus resulting in low-energy consumption and good energy efficiency.

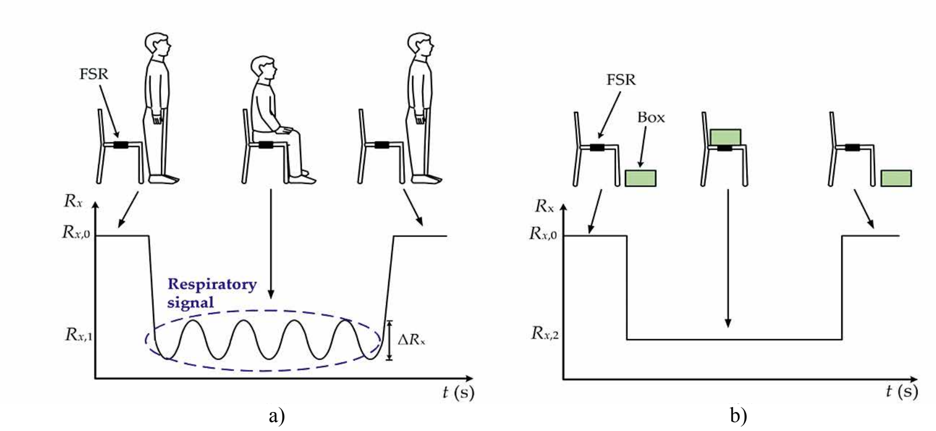


Figure 8 Display of signal variations when a person (a) or an object (b) is on the chair (Sifuentes *et al*., 2019)
Slika 8. Prikaz varijacije signala kada je na stolici osoba (a) ili predmet (b) (Sifuentes *et al*., 2019.)

Therefore, the present method can be attractive for autonomous sensor applications that require the detection and confirmation of people sitting in chairs, such as intelligent airbag deployment systems and aircraft boarding systems.

Offices are not the only places that can be enhanced with smart seating. Smart home environment is more and more present in our daily life, and smart chairs become an unavoidable item of that system (Hesse *et al.,* 2017). The presented chair development is a part of the wider project where parties involved from industry, research (…) and health providers address the question of how "intelligent" and "trustworthy" technical systems

Figure 9 Smart chair with integrated sensors locations (F – FSR, R – radar) (Hesse *et al*., 2017)
Slika 9. Pametna stolica s rasporedom integriranih senzora (Hesse *et al*., 2017.)

can be realised to help people in their everyday lives. In terms of the above, smart armchair is an example of ubiquitous interaction system with the goal to improve the user's well-being (Figure 9).

The integrated sensors and actuators enable a multiplicity of applications. The sensors in the seating can be used for presence detection, they can serve as simple push buttons and form an input device, and user's posture can be determined by analysing patterns in the sensor data that can be used to emphasise a healthy sitting posture, etc. The integrated radar sensor can measure the movements of the body caused by the heart beating and respiration, and therefore it can be used to calculate the respiration rate and heart rate. With these, contactless acquired data, it is possible to track the user's health status, detect potentially harmful conditions and provide biofeedback for the relaxation modes. The actuators are used to assist the user while sitting down or standing up, which is especially important for elderly people, or can be used to adjust the chair to the actual user's need. Information about the individual needs is based on the identification of the user and can be gathered from the connected database. The introduced applications are potentially able to improve the user's well-being by offering qualified fitness training, a relaxation mode and assistive functions. Additional value of this research and system is generated by connecting the chair to a smart home environment, which enables and expands novel features and use.

Hu *et al.* (2020) presented a smart chair sitting posture recognition system using flex sensors and implemented artificial neural network that can categorise seven different health-related sitting postures. This research introduces flex sensors with a machine learning algorithm to build a low-complexity hardware system for sitting posture recognition, in which only six passive flex sensors are attached to the chair (Figure 10).

Comparing their system with the state-of-the-art works, the authors conclude that this work has achieved

Figure 10 Flex sensor based sitting posture recognition system (Hu *et al*., 2020)
Slika 10. Sustav za prepoznavanje sjedećeg položaja uz pomoć senzora savijanja (Hu *et al*., 2020.)

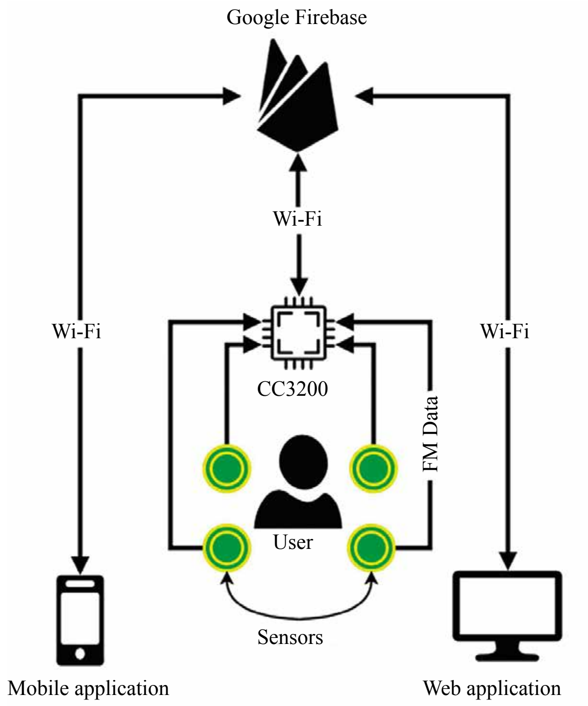


Figure 11 General architecture of Smart Chair system (Flutur *et al*., 2019)
Slika 11. Opća arhitektura sustava Smart Chair (Flutur *et al*., 2019.)

the lowest power consumption, the greatest hardware simplicity and the highest accuracy among the related works. The primary novelty of this research is the new type of sensor combined with fixed-point two-layer artificial neural network model developed to achieve the above goals. The proposed system brings longer battery life, better user experience, and robustness compared to other types of sensing systems. In the future work of these authors, this recognition system will be a part of a smart health monitoring system, which will consider the algorithms with complicated architecture like convolutional neural network.

Flutur *et al.* (2019) developed a smart chair system for posture correction based on a capacitive proximity transducer type of the sensor for remote monitoring. This is a chip-based system. The microcontroller unit measures the frequency signal of each sensor and then sends the data to a Google Firebase cloud via Wi-Fi (Figure 11).

When the subject is in contact with the sensors, the data is correlated with the actual pressure, and when the contact is absent, the measurements data are correlated with distance. In order to collect relevant readings in real-time for the human body position, the capacitive/proximity sensors were placed in six key points: two on the chair seat and four on the user back. To understand in which way and at which time the user is adopting a correct or incorrect posture, he or she can use the data presented in an easy to understand way on mobile application. For the purpose of the present research, it was important to create the user interface so that he/she can easily interact with the information provided by the sensors. The uniqueness of this design for correcting postures comes not from the use of sensors, but the individuality of each feature. The sensors were specifically designed and created for this particular use. The mobile application and the web interface provide ease of access and also a high rate of commodity when using the device.

Design and implementation of a smart chair system for IoT is observed in a research of Park *et al.* (2016), where the system combining a built-in IoT device and a chair with separated seating pads was presented. According to authors, by using “smart IoT chair”, the posture can be easily corrected by checking the user’s posture on a smart device (phone). Collected posture data can be used for example to further understand user’s sitting habits, correct children’s posture promoting healthy growth, provide medical information and analyse the time and pattern during studying or working. The system works on the principle of sensing user posture by an embedded IoT device and sev-

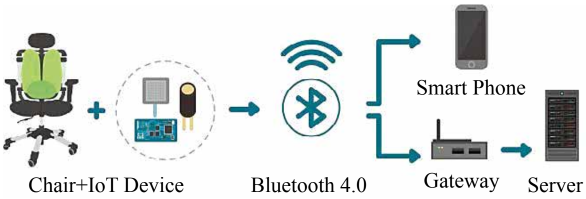


Figure 12 Overview of "Smart IoT Chair" system (Park *et al*., 2016)
Slika 12. Pregled sustava *Smart IoT Chair* (Park *et al*., 2016.)

eral custom designed sensors that are attached to the chair. The embedded IoT device, using Bluetooth technology, sends measured sensor data to a smartphone or a server. At the end, either the server or the smartphone receives, processes, and visualises the posture data sent by the "smart IoT chair" system in real-time (Figure 12). Besides that, a wireless gateway can be used to analyse the pattern of an individual (or groups) and send analysed data to the server by processing data received from a number of smart IoT chairs.

In the smartphone application, the user can visually check his posture, where circles in four colours represent the four levels of pressure sensed by the four pressure sensors, while the four levels of sensed tilt are represented by the tilting of the pad in the figure of the chair itself. Furthermore, actual level values of each sensor are displayed at the bottom of the application. During the research, the limitations were additionally discovered of the existing (off-the-shelf) commercial sensors (pressure, flexible and tilt) and these problems were overcome by developing custom designed sensors.

Different subjects have their distinctive heartbeat patterns due to differences in age, gender, weight, cardiac structure, etc. The heartbeat-based human identification has shown some advantages, basically in resistance against malicious cyber-attacks. A heartbeat is the vibration caused by the passage of blood from the cardiac atria to the ventricles and from the heart cells to the aorta and pulmonary artery (Guyton and Hall, 2012). The heartbeat presents a unique life indicator to represent a subject and it is difficult to manipulate or replicate, and can be represented by ballistocardiography (BCG). BCG is a method of recording the displacement of the body during the ejection of blood from the heart into the aorta at each cardiac contraction. However, the normal record of body displacement changes in some heart patients (aortic stenosis and insufficiency) (***, 2021).

The work of Zhang *et al.* (2019) experimentally presents the unobtrusive continuous identification of a person by BCG using a sensor that works on the principle of micro-bending of the optical fibre (Figure 13).

The authors believe that such a way of identifying a person is appropriate as a person just needs to sit down, lean back, and the chair will recognise who it is. The main goal of this research was to develop a pillow with a sensor to identify a person leaning on a pillow that monitors BCG signals. At the same time, microbending of the optical fibre takes place in the sensor and vibrations are read, including the heartbeat. Experimental results show that the filtered BCG signal reveals an individual pattern of BCG signal. The main advantage of this method of identification in relation to the ECG is that it is much easier and simpler for a person to just sit and lean on a pillow than to be connected to various electrodes.

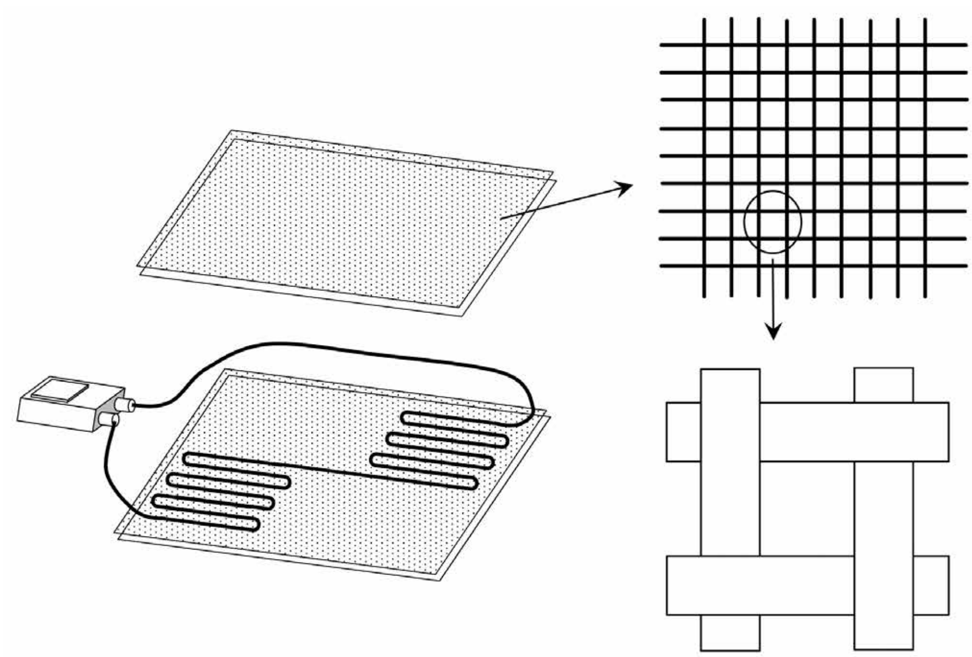


Figure 13 Schematic of microbend fibre sensor (Zhang *et al*., 2019)
Slika 13. Shematski prikaz senzora s mikrosavitljivim vlaknima (Zhang *et al*., 2019.)

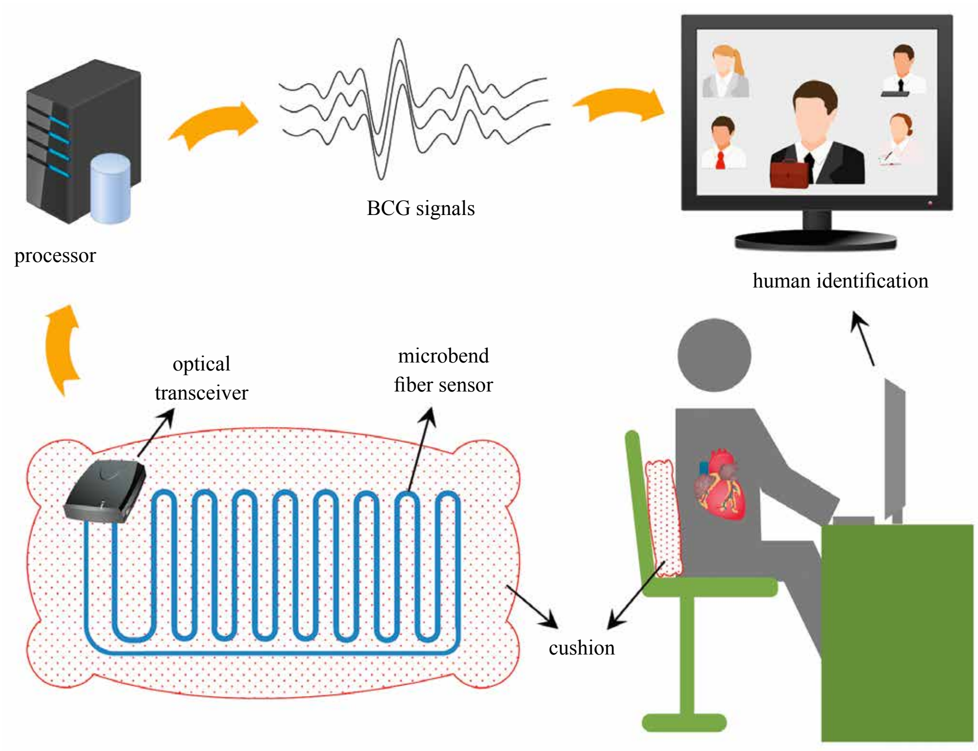


Figure 14 System architecture of continuous human identification system (Zhang *et al*., 2019)
Slika 14. Arhitektura sustava za kontinuiranu identifikaciju ljudi (Zhang *et al*., 2019.)

Figure 14 schematically shows the operation of a pillow for identifying a person, where the convenience and ease of use of such a pillow can be best seen. The authors recommend biometric identification of humans using BCG and prove in their paper that continuous and good recognition results have been obtained. They also emphasise that this is a biometric recognition method that is harder to hack, so it can be used in much more delicate conditions (e.g. military use). It is interesting to mention that the authors conducted an additional experiment where it was found that this method can unlock a smartphone.

However, there are studies that have tried to overcome the problem of contact measurement of electrocardiogram signals, i.e. reducing the occurrence of errors in measurements by combining both BCG and ECG. Ahn *et al.* (2015) developed a smart chair based on multi heart rate detection system. The smart chair implementation is designed to measure a non-contact ECG and an unconstrained BCG at the same time (Figure 15).

The aim was to make up for the shortcomings of the two types of spectrum. The authors succeeded in implementing a non-contact ECG measurement without the need to place electrodes on the body, i.e. while the person is dressed; furthermore BCG provides the possibility of unlimited measurements. In addition, the advantage of such a measurement is that the sitting position does not affect the quality or result of the measurement. However, there are many disadvantages due to the appearance of "noise" in the movements. For non-contact ECG measurements, electrodes are arranged on the contact surfaces of the backrest and seats, i.e. the user's back and buttocks. The BCG measuring system consists of a loadcell located under the

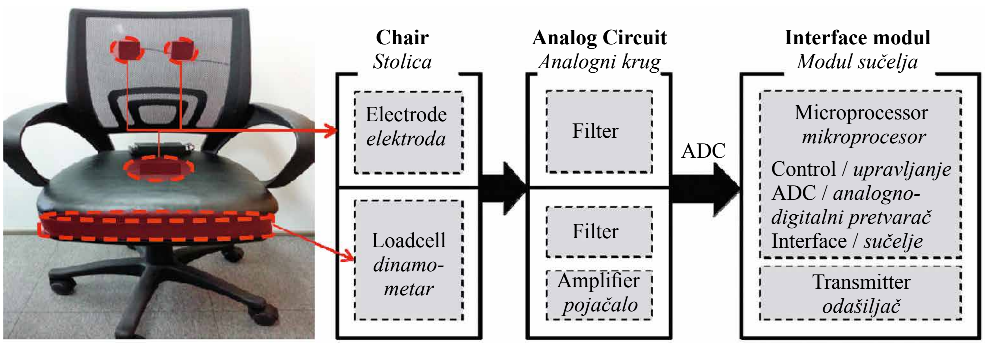


Figure 15 Smart chair system configuration based on heart rate detection system (Ahn *et al*., 2015)
Slika 15. Konfiguracija sustava pametne stolice utemeljena na sustavu za detekciju broja otkucaja srca (Ahn *et al*., 2015.)

seat base to measure the change in weight. The measurement signal is transmitted to the Android smartphone in real time. The authors find that the presented unique and simultaneous measurements of ECG and BCG signals reduce the disadvantages of their separate measurements.

Sodhi and Kunwar (2017) research was motivated by the infinite possibilities provided by the concept of *Inernet of Things* to make surroundings better and smarter. As the research was placed in educational environment, the goal of the *Smart Chair* concept was to verify the presence of a human being and to automate the attendance process in the classroom suggesting the student to maintain a healthy sitting posture. *Smart Chair* helps in the identification of the student and it uses pressure and temperature sensors to maintain the presence record of the student in a local database. It also signals the students to maintain right posture for their healthy lifestyle. The presented prototype of the smart chair system consists of a microcontroller board-based system, which is assembled and implemented to get user ID through radio frequency identification reader and chair occupancy status by pressure sensor and temperature sensor. Moreover, the chair is also equipped with a micro-electromechanical system (MEMS), a 3-axis accelerometer which is used to check the posture of the body and to recommend changing the body posture if the posture is not correct. The functionality of MEMS is not clearly described, but it works on the principle of previously set values for "normal range", i.e. "for the correct body posture", and any other values that are later considered as "not correct postures".

All processed papers on "smart chairs" or "sensors chairs" are shown in Table 1, where an overview of the used sensors, methods of data processing, system accuracy and other summary data are given.

4 CONCLUSIONS
4. ZAKLJUČAK

There is no doubt that mass digitalisation will change the way we live and work.

Industry 4.0 and IoT provide great and new opportunities to improve the world we live in, and can help discover solutions to the great challenges that these new opportunities pose. One of possible and positive improvement could be used for observing our unconscious habits while sitting and working. We will have to tackle the problem of improper sitting and its impact on people's health for many years to come. Nevertheless, it has been shown that the use of modern technology and a better understanding of sitting using a variety of sensors and applications can act preventively in most situations.

This paper singles out 15 current studies whose methods and results are briefly explained in the previous chapter. The selected papers describe various sensors, such as: force-sensitive resistor, heart rate sensor, respiratory monitoring sensor, voice control sensor and acceleration sensor. The system for observing the way of sitting, collecting and processing data and displaying them in real time brings the best results, because in this way it directly influences the user to change the position or keep it. The presented solutions include various applied technologies, ways of functioning and outcomes. Diversity is good and acceptable, but it can cause certain problems, especially if it is not standardised. That has been the case in many of the presented sensor technology solutions that are not always compatible with each other. One of the solutions for wider application and faster implementation of sensor technologies in everyday use in work or home chairs would be the introduction of certain standards that would overcome the obstacles of matching different user needs into a single monitoring system.

Problems that will arise in the future could be related to the acceptance of such built-in monitors by users, mostly due to the risk of invading privacy. There are also possible dangers of malicious intrusions into systems (hacking). Current pandemic problems with poor availability of electronic components (chipsets) due to disrupted supply chains could further slowdown wider implementation of such furniture in everyday life, meaning high prices and low availability on the market. The examples of technologies in this paper show that the previous ideas of "smart furniture" are now functional solutions, but they need to be improved so as to be simpler for installation in furniture, less noticeable and more user friendly.

In future, it should be compared the types of sensors, the methods used and the results obtained in order to determine in which direction the development of certain types of "smart" seating furniture will take place, with emphasis on healthy seating while working.

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Table 1 Related articles on "smart chairs" or "sensors chairs" systems
Tablica 1. Članci koji se odnose na sustave pametnih stolica ili stolica sa senzorima

Chair type *Vrsta stolice*	**Sensor(s) type, quantity, (location)** *Vrsta i broj senzora (lokacija)*	**Data acquisition and processing** *Prikupljanje i obrada podataka*	**Classification method(s)** *Metode klasifikacije*	**User interface/application (connection)** *Korisničko sučelje/aplikacija (veza)*	**Accu-racy** *Točnost*	**Authors** *Autori*
office chair / *uredska stolica*	FSR sensor: 4 (on the seat), 2 (on the backrest) *FSR senzori: 4 (na sjedalu), 2 (na naslonu)*	A/D converter MCP 3008, Raspberry Pi	RF; ERT; SVM	n/a	98 %	Lee *et al.*, 2019
wheelchair / *invalidska kolica*	FSR sensor: 6 (on the seat, in the cushion); 3-axis inertial: 1 (in the cushion) *FSR senzori: 6 (na sjedalu, u jastuku);* *3-osni inercijski (u jastuku)*	Arduino Pro Mini	AAI; BPAM; J48	computer, smartphone, tablet (Bluetooth) *računalo, pametni telefon, tablet*	89-98 %	Ma *et al.*, 2017
office (gaming) chair / *uredska stolica*	capacitive sensors: (in the seat and in the backrest); PPG and ECG sensors (under the armrest) *kapacitivni senzori: (u sjedalu i naslonu);* *PPG i ECG senzori (ispod naslona za ruku)*	microcontroller	ECG R-wave peaks; PTTs	mobile devices *mobilni uređaji*	N/A	Zazula *et al.*, 2015
office chair / *uredska stolica*	force sensors: 6 (at the seat), 4 (at the backrest) *senzori sile: 6 (na sjedalu), 4 (na naslonu)*	microcontroller ESPino32, Arduino, cross platform database MongoDB	SVM; Bernoulli; Gaussian; MLP Classifier and Logistic Regression	mobile devices (Bluetooth) *mobilni uređaji*	96.2 %	Prueksanusak *et al.*, 2019
regular chair / *obična stolica*	FSR sensors: 4 (on the backrest) *FSR senzori: 4 (na naslonu)*	RFduino	ERT	mobile devices or another RFduino (Bluetooth) *mobilni uređaji ili neki drugi RFduino*	86 %	Kumar *et al.*, 2016
n/a	RFID EM-18; single point load cell sensor ESP 4-150; LM35 temperature sensor; MEMS *senzor opterećenja u jednoj točki ESP 4-150; LM35 senzor temperature*	microcontroller PIC;	pressure of body; body heat	LCD, Web application (wireless) *mrežna aplikacija (bežična)*	n/a	Sodhi and Kunwar, 2017
n/a	FPS with piezoresistive conductive film: 4 (at the seat), 2 (at the backrest) *FPS senzori s piezootpornim konduktivnim filmom: 4 (na sjedalu), 2 (na naslonu)*	Arduino Nano ATMega328	pressure of body *pritisak tijela*	mobile devices (Bluetooth) *mobilni uređaji*	n/a	Anwary *et al.*, 2019
n/a (only cover cushion) / (*samo dodatni jastuk*)	FSR sensor: 30 on the seat (in the cushion), 30 on the backrest (in the cushion) *FSR senzori: 30 na sjedalu (u jastuku), 30 na naslonu (u jastuku)*	Arduino	pressure of body *pritisak tijela*	mobile devices (Bluetooth) mobilni uređaji	n/a	Kim and Lim, 2019

office chair / *uredska stolica*	FSR sensor: FSR406: 1 (on the seat centre) *FSR senzor: FSR406: 1 (na sredini sjedala)*	Texas instruments MSP430F123 (MCU) applying direct interface circuit (DIC) concept	pressure of subject/object *pritisak subjekta/objekta*	n/a	n/a	Sifuentes *et al.*, 2019
reclining armchair / *naslonjač za opuštanje*	FSR sensor integrated in fabric: FSR406: 7 (in the seat), 2 (in the footrest), 1 (in the backrest); FSR sensor: FSR408: 2 (in armrests); GSR sensor; radar sensor *FSR senzori integrirani u tvornici: FSR406: 7 (na sjedalu), 2 (na podestu za noge), 1 (na naslonu); FSR senzori: FSR408: 2 (na naslonu za ruke); GSR senzor; radarski senzor*	microcontroller: ATSAM-4LC4C, ADC: ADS7953, operational amplifier: MCP6241T; depth camera (Microsoft Kinect); smart watch (heart rate monitor)	pressure of subject; presence of subject *pritisak subjekta; prisutnost subjekta*	TV screen *TV ekran*	n/a	Hesse *et al.*, 2017
office chair / *uredska stolica*	FSR sensor: FS-L-0055-253-ST: 3 (on the seat), 1 (on the backrest), 2 (on the armrests) *FSR senzori: FS-L-0055-253-ST: 3 (na sjedalu), 1 (na naslonu), 2 (na naslonu za ruku)*	Arduino board, ADC board	ANN two-layer; SVM	PC	97.4 % – 97,8 % 88.4 %	Hu *et al.*, 2020
n/a	capacitive proximity transducer: 2 (on the chair seat), 4 (on the user back) *kapacitivni senzor blizine: 2 (na sjedalu stolice), 4 (na leđima korisnika)*	SoC: MCU CC3200; Google Firebase Cloud; OpenEHR	n/a	web and mobile applications *mrežne i mobilne aplikacije*	n/a	Flutur *et al.*, 2019
seating pads (in office chair) / *podlošci (jastuci) za sjedenje*	custom made pressure sensors: 6 (on the seat) 4-level analogue tilt sensor: 2 (under the seat) *senzori tlaka izrađeni po mjeri: 6 (na sjedalu) 4-razinski analogni senzor nagiba: 2 (ispod sjedala)*	Arduino Pro mini; DAC; communication BT module: HM-10	n/a	iOS smart device or a gateway (Bluetooth 4.0, iBeacon) *iOS pametni uređaj ili pristupnik*	n/a	Park *et al.*, 2016
free-cushion (on the backrest) / *slobodni jastuk (na naslonu)*	microbend multi-mode optical fibre sensor *senzori optičkih vlakana*	n/a	LDA; MC-SVM; 1D-CNN	n/a	n/a	Zhang *et al.*, 2019
office chair / *uredska stolica*	non-constrained ECG electrode PS25255; BCG measuring system: SB S-beam loadcell *EKG elektroda bez ograničenja PS25255; BCG mjerni sustav*	MCU ATmega8L; BT module: HC-06	n/a	Android smart device or PC (Bluetooth, Wi-Fi) *Android pametni uređaj ili računalo*	n/a	Ahn *et al.*, 2015

FSR – force-sensitive resistors / *otpornici osjetljivi na silu;* PPG – photoplethysmography / *fotopletizmografija;* ECG – electrocardiography / *elektrokardiografija;* RFID – radio frequency identification / *identifikacija radiofrekvencijom;* MEMS – microelectromechanical systems / *mikroelektromehanički sustavi* ; FPS – flexible pressure sensor / *savitljivi senzor tlaka;* GSR – galvanic skin response sensor / *galvanski senzor reakcije kože;* BCG – ballistocardiography *balistokardiografija*
RF – random forest / *slučajna šuma;* ERT – extremely randomised trees / *ekstremno slučajne šume;* SVM – support vector machine / *stroj s potpornim vektorima;* AAI – activity assessment index / *indeks procjene aktivnosti;* BPAM – body posture analysis model / *model analize držanja tijela;* PTTs – pulse; transit times / *prolazna vremena pulsa;* MLP – multi-layer perceptron / *višeslojni perceptron;* ANN – artificial neural network / *umjetne neuronske mreže;* LDA – linear discriminant analysis / *linearna diskriminantna analiza;* MC-SVM – multi-class support vector machine / *višeklasni stroj s potpornim vektorima;* 1D-CNN – one-dimensional convolutional neural network / *jednodimenzionalna konvolucijska neuronska mreža*

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