Review

Smart-Sensing Chairs for Sitting Posture Detection, Classification and Monitoring: A Systematic Literature Review

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**Abstract:** Improper sitting posture is the act of sitting in an asymmetric or an uneven way. If maintained for an extended period, it can negatively affect one’s wellbeing and can lead to long-term health conditions such as spinal deformity and musculoskeletal disorders. With the current advancement in sensor technology, there are different methods that are being employed within the research sphere with hopes of tackling improper sitting postures. This study aims to systematically review some of the existing literature to shed some insight into the common approaches being adopted in the detection and classification of improper sitting postures. Over the past 2 decades, various research studies have explored the concept of a smart sensing chair in the monitoring of sitting postures. Furthermore, an in-depth search was conducted across 3 main research databases which were MDPI, IEEE, and Google Scholar. The selection criteria primarily focused on studies that used non-invasive means in the monitoring of sitting postures. After filtering out all the irrelevant and duplicated articles, there were a total of 33 research articles and journals identified. Overall, it was observed that the Force Sensing Resistor (FSR) is the commonly used sensor for sitting posture detections. Additionally, the CNN (Convolutional Neural Networks) and the ANN (Artificial Neural Networks) were 2 of the most used machine learning models for sitting posture classification. The reviewed studies also highlighted a gap within the research field, revealing that a significant emphasis is drawn on the validating the proposed sitting posture algorithm, while the critical evaluation on the user feedback system for posture correction is often dismissed upon.

**Keywords:** smart sensing chair; musculoskeletal disorders; sitting posture classification

1. Introduction

In 2020 alone, musculoskeletal disorders (MSDs) were ranked as the second leading cause of non-fatal disability, affecting over a billion people globally [1]. In the United Kingdom alone, more than 7.1 million adults suffer from MSDs, imposing an economic burden exceeding £4.1billion annually. Bevan et al. (2015) [2] highlighted that MSDs account for over 2% of the European Union’s gross domestic product (GDP), translating to an annual cost of approximately €240 billion. These statistics underscore the increasing concern surrounding MSDs, necessitating effective interventions.

MSDs arise from a variety of factors, ranging from congenital defects [3] to neurological disorders [4]. Contrary to common misconception, MSDs are not confined to the elderly; individuals of all ages are susceptible. Early development of MSDs can be attributed to sedentary lifestyles and poor posture [5]. The office environment, characterized by prolonged periods of sitting, can exacerbate the risk of developing long-term musculoskeletal conditions, including back pain and spinal deformities [6–8]. Studies conducted among daily office workers conclude that there is a strong correlation between prolonged sitting and severe back pains affecting the lumbar area [9,10]. To combat this problem, a recommendation is that the users take stroll breaks every few hours. The incorporation of exercise breaks as a daily routine, potentially increases cognitive functions in the long-term and improves muscle strength [11].

Poor sitting posture has long been recognized as a significant contributor to the development of pressure sores, adversely affecting the function, comfort, physiology, and mobility of individuals who use wheelchairs [12]. Healthcare professionals tasked with conducting postural assessments often rely on external observations to infer the internal configuration of musculoskeletal structures [13]. Typically performed in clinical settings, these assessments are subjective, with the detection of abnormalities dependent on visual inspection [14]. Objective techniques for measuring musculoskeletal configuration such as MRI, CT scans, and X-rays are accurate but impractical for routine clinical use due to logistical, cost, and safety considerations, notably the risk of increased radiation exposure. Over the years, a diverse array of techniques for anthropometric measurements and postural assessments has been developed, broadly categorized into contact and non- contact methods. The contact methods include simple tactile devices such as anthropometric tapes, stadiometers or scoliometers [15]. Non-contact techniques are radiography [16], Moire fringe topography [17], structured light methods [17], laser scanning [18], pressure mapping systems [19], mechanical displacement sensors [20] and ultrasonic localization [21]. The primary drawbacks of tactile devices are their time-intensive nature, the absence of three-dimensional (3D) data, and potential discomfort for the patient. Non-contact methods, on the other hand, tend to offer enhanced accuracy and frequently provide 3D shape information. Yet, a significant limitation of these non-contact methods, particularly in the context of assessing sitting posture, is their dependence on direct access to the individual’s back. This necessitates the person to be in an upright, standing position for the measurement process, posing challenges for evaluations conducted in a seated posture.

Smart sensing chairs offer a solution to the limitations inherent in both contact and non-contact methods of assessing sitting posture. By integrating sensors directly into the seating surface and backrest, these chairs enable continuous, real-time monitoring of posture without the need for direct physical contact or the subject to be in a specific position, such as standing. Furthermore, the incorporation of smart sensing chairs into home or office environments enables active monitoring and feedback on user’s health and activity levels. With the recent development in sensor technology and Artificial Intelligence, these systems hold promise for advancing personalized healthcare and enhancing quality of life, particularly for individuals afflicted with musculoskeletal disorders (MSDs).

The concept of a smart sensing chair was first explored by Tan et al. (2001) [22], pioneering the classification of sitting postures using integrated pressure sensors. Recent years have witnessed a surge in research focusing on smart sensing chairs, with approximately 500 studies published annually over the past five years. This trend underscores the growing interest in the field, highlighting the continuous increase in related publications.

The primary aim of this literature review study is to evaluate published papers on smart sensing chair systems, aiming to understand the methods being employed in posture classification. By exploring existing studies, it is possible to analyse current trends such as commonly used sensors and machine learning algorithms being adopted as well as potential research gaps. Ultimately, this review paper aims to provide valuable insight for researchers in the development of non-invasive smart sensing chair systems.

2. Research Methodology

This paper is aimed at conducting a systematic review of similar research studies done on smart sensing chair technology. Overall, there are 7 steps involved with this systematic review process which is the following: 1. Formulation of Research Questions 2. Search Strategy, 3. Study Screening and Selection, 4. Data Extraction, 5. Discussion, 6. Conclusion and Recommendations.

2.1 Formulation of Research Questions

Table 1 presents the research questions for the systematic literature review on smart sensing chairs, each accompanied by its underlying rationale. These questions have been crafted to guide a literature review of smart sensing chairs, targeting key aspects that are central to understanding the current state and future directions of this technology.

**Table 1.** Research Questions

|  |  |
| --- | --- |
| **ID** | **Research Question and Rationale** |
| RQ1 | In the context of posture detection, what are the most used sensors in smart sensing chair studies, and how do they compare in terms of accuracy and reliability?  **Rationale:** This question aims to uncover common trends in sensor technology, which can  inform the development of more effective and sensitive smart chairs for posture detection. |
| RQ2 | What methods are being used to classify different sitting postures?  **Rationale:** This question addresses the computational approaches employed to process sensor data, which is essential for the effective classification of sitting postures.  Understanding the methods used can highlight the most successful strategies and potential areas for innovation in posture classification algorithms. |
| RQ3 | What technological, methodological, and application-based limitations and research gaps are identified in the current literature on smart sensing chairs?  **Rationale:** This question seeks to pinpoint the shortcomings of current studies on smart  sensing chairs, laying the groundwork for future research to address these areas. |
| RQ4 | What user feedback mechanisms are implemented in smart sensing chairs, and how do they impact user satisfaction and posture correction outcomes?  **Rationale**: The incorporation of user feedback mechanisms is critical for the practical application of smart sensing chairs, influencing user compliance and the effectiveness of posture correction strategies. This question focuses on the interaction between users and the technology, a key factor in the adoption and success of these systems. |
|  |  |

2.2 Search Strategy

A comprehensive search was conducted across several academic databases, including Google Scholar, IEEE Xplore, and MDPI, to gather relevant articles. A predefined set of keywords and combinations thereof were used to refine the search, ensuring the retrieval of pertinent studies published in the last two decades. Table 2 outlines the search keywords.

**Table 2.** List of Search Keywords

|  |  |
| --- | --- |
| **ID** | **Keywords** |
| SK1 | Smart Sensing Chair |
| SK2 | Sitting Posture Recognition |
| SK3 | Posture Classification |
| SK4 | Sitting Posture Classification using Machine Learning |
| SK5 | Sitting Posture Monitoring |
| SK6 | Sitting Posture Detection |
|  |  |

2.3 Study Screening and Selection

The initial screening was based on the relevance of the titles and abstracts to the research questions. Studies published within the last 20 years were considered, applying exclusion criteria to omit research using invasive methods for posture classification. The selection process, illustrated in Figure 2, resulted in a total of 33 pertinent papers.

A diagram of a research process

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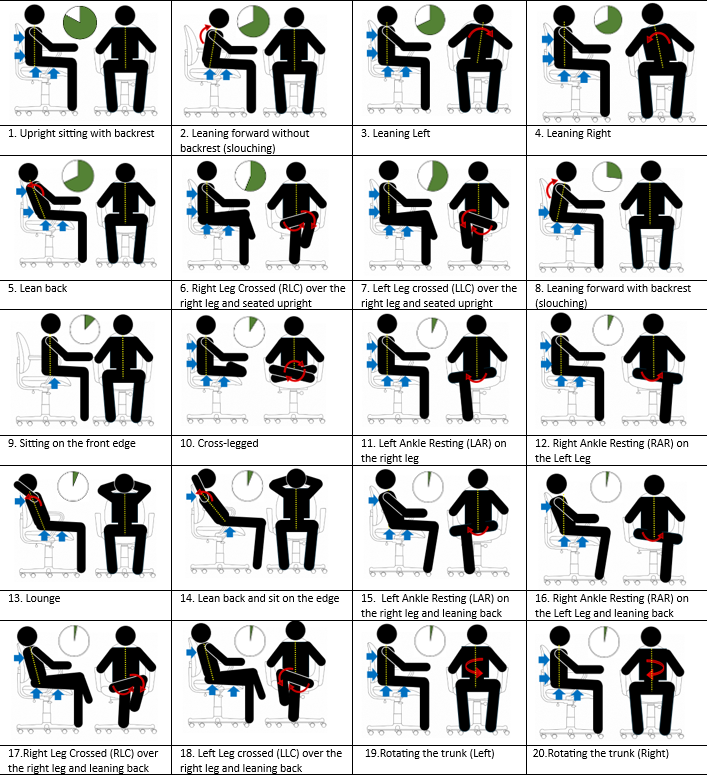
**Figure 2**. Literature Review Process

2.4 Data Extraction

The data extraction phase is primarily focused on extracting the relevant information from the research papers gathered. This was achieved by individually reading through each paper in hopes of gathering useful data, especially on the methods and techniques being employed in the development of a smart sensing chair system. Listed below are the following information that was captured while going through each research paper: Authors, Published Year, Sensors Used, Sensor Placement, Number of Postures Classified, Recognized Postures, Classification Method, Classification Accuracy, Limitations, User Feedback System, Realtime, and Method Used.

3. Sitting posture selection

The concept of an “ideal” sitting posture is inherently subjective, reflecting significant variation across diverse groups. Particularly for individuals with permanent mobility impairments or those who use wheelchairs, the parameters defining a comfortable sitting posture are distinctly unique. While the conventional wisdom among healthcare professionals’ advocates for an upright lordotic spinal position, the inherent variability in spinal anatomy across individuals challenges the notion of a one-size-fits-all “correct” posture [23]. Biomechanical research has shed light on the consequences of various sitting positions on spinal alignment and muscle engagement, emphasizing the musculoskeletal stress induced by inadequate postures [24–26]. These investigations reveal that extended periods of sitting, especially in a slumped position, intensify the symptoms of musculoskeletal disorders and are a contributing factor to lower back pain. Moreover, recommendations consistently suggest minimizing prolonged sitting durations, regardless of whether the posture is upright or slouched, to mitigate potential health risks. Korakakis et al. [24] underscored the absence of conclusive medical evidence associating any particular sitting posture with enhanced health benefits, further complicating the pursuit of an optimal sitting strategy. Figure 1 presents 20 sitting postures detected by smart sensing chair systems as reported in the literature, with the relative prevalence of each posture depicted through a pie chart. This pie chart quantifies the percentage of review papers that have investigated each specific posture, ranking these postures from the most to the least frequently detected by such systems. Blue arrows highlight the primary pressure points at the interface between the seat and the occupant, while red arrows delineate the direction of adjustments necessary for adopting each specific posture. The most popular sitting postures detected by the smart sensing chairs include 1. Upright sitting with backrest, 2. Leaning forward with backrest (slouching) 3. Leaning forward without backrest (slouching), 4. Sitting on the front edge 5. Leaning Left 6. Leaning Right reported by the majority of studies.



**Figure 2**. 20 categories of different sitting postures along with a pie chart indicating its popularity among the research studies found.

4. Technologies Used in Smart Sensing Chairs

4.1 Sensor Technologies

Currently, there are other types of sensors being used in the development of smart sensing chairs ranging from pressure sensors to image-based sensors. Furthermore, this section aims to review the variety of sensor technologies being integrated into smart sensing chairs system; each offering its unique benefits and challenges in the classification of sitting postures.



**Figure 3**. Taxonomy Graph of sensors used in smart sensing chair systems.

4.1.1 Force Sensing/Sensitive Sensor (FSR)

Force Sensing Resistors, also known as force sensors, are commonly used to measure the forces and physical pressure applied to its surface area. These sensors work by varying their output resistance based on the pressure being applied to it. A FSR sensor is typically composed of a conductive polymer-based material that is integrated between 2 metal electrodes [25]. Typically, the conductive material changes in resistivity as more direct pressure are applied on the sensor’s z-axis. FSR sensors are also known to be very cost-effective and have been utilized in various fields ranging from robotics to medical applications [26]. However, the main limitation seen with these sensors is that it can be susceptible to drift errors which can negatively affect the accuracy of its readings. There are different methods such as sensor calibration and other advanced force computing techniques to mitigate this issue [27]. Listed in Table 3 are some of the commercially available FSR sensors as well as some of its technical specifications.

|  |  |
| --- | --- |
| A ruler next to a square piece of electronic device  Description automatically generated | A measuring device next to a ruler |
| (**a**) | (**b**) |

**Figure 4.** Examples of FSR sensors (**a**) Square shaped FSR sensor (FSR01CE) [28]; (**b**) Circle shaped FSR sensor (FSR03CE) [28].

**Table 3.** Technical specifications on FSR Sensors commercially available

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Model** | **Manufacturer** | **Dimensions**  **(Length x Width, Thickness) (mm)** | **Force Sensitivity Range (Newtons)** |  |
| FSR 402 [29] | Interlink Electronics | 14.68 x 14.68 x 0.46 | 0.1 - 100N |  |
| FSR 406 [30] | Interlink Electronics | 39.6 x 39.6 x 0.46 | 0.1 – 100N |  |
| FSR01CE [28] | Ohmite | 39.70 x 39.70 x 0.375 | Up till 49 N |  |

4.1.2 Textile Pressure Sensor

A textile-based pressure sensor is typically composed of a soft fabric-based material which consists of a conductive thread pattern placed over a dielectric material that serves as a substrate between the threads [21]. Figure 5a visualises an example of how each layer within the textile pressure sensor is structured within. One of the main advantages seen with textile force sensors is the fact that it is very durable, and it seamlessly integrates with garments making it unobstructive and comfortable to the end user. Hence, the reason this sensor tends to be more popular among wearable technologies.

|  |  |
| --- | --- |
| Sensors 18 01190 g001 | A black square with white lines on it  Description automatically generated |
| (**a**) | (**b**) |

**Figure 5**. Textile Pressure Sensor (a) Textile Pressure Sensor composition [31]; (b) PreCaTex textile sensor [32].

There were a few research studies found that employed textile pressure sensors to classify sitting postures. One of which was Kim et al [33] who developed a washable textile pressure sensor and incorporated it into their chair system to classify 7 sitting postures using a decision algorithm. Another study proposed a “eCushion” device which incorporated an “eTextile” pressure sensor array that can detect 7 different sitting postures at 85.9% accuracy [34]. Additionally, Martínez-Estrada et al [32] developed 10 detachable textile pressure sensor (PreCaTex) which were placed at strategic points around the chair.

4.1.3 Load Cells

Load cells are another variation of force sensor which is used among researchers in the monitoring of sitting postures. A load cell sensor works by converting applied mechanical force into measurable digital signals which can be read by microcontrollers. Currently, there are different types of load cells such as strain gauge, piezoelectric, hydraulic, and capacitive load cells [35].

Some of the commercially available load cell sensors can be found in Table 4 below.

**Table 4.** Technical specifications on Load cells Sensors commercially available

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Model** | **Manufacturer** | **Dimensions**  **(Length x Width) (mm)** | **Capacity (kg)** |  |
| SEN-10245 [29] | SparkFun Electronics | 34 x 34 | 40-50 |  |
| P0236-142 [36] | Hanjin Data Corps | 34 x 34 | - |  |

The use of load cells is not a popular option among research studies, so far only 2 research studies that implemented load cells in their smart sitting systems. Roh et al. in 2018 [36] developed a smart chair by integrating 4 load cell sensors within the chair sitting cushion to classify 6 sitting postures. An accuracy of 97.94% was achieved using a SVM (RBF kernel) ML model. Similarly, Pereira and Plácido da Silva in 2023 [37] distributed 3 load cells across the seat’s cushion in order to classify 8 sitting postures; overall they were able to a classification accuracy of 98.50%.

4.1.4 Flex Sensors

A flex sensor, also known as a bend sensor, works by measuring the degree of displacement resulting from the bending action being applied to the sensor. Currently, it is being used in various applications from robotics to medical devices. There are multiple types of flex sensors in the market, however it is the conductive ink-based flex sensors that are widely popular among robotics projects. These flex sensors are typically composed of a flexible composite material which has a conductive ink material which changes in resistance as the sensor is being bent [38].

**Table 5.** Technical specifications on Flex Sensors commercially available

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Model** | **Manufacturer** | **Dimensions**  **(Length x Width) (mm)** | **Flat Resistance** |  |
| FS-L-055-253-ST [39] | Spectra Symbol | 112.24 x 6.35 | 10K Ohms |  |
| Flex Sensor 2.2 [40] | Spectra Symbol | 73.66 x 6.35 | 25K Ohms |  |

Overall, there were only 2 studies identified that utilized this method for sitting posture detection. The first was by Hu et al [41] who developed a smart sensing chair using 6 flex sensors and a 2-layer Artificial neural network (ANN) for detecting 7 sitting postures and achieved an accuracy of 97.43%. The second was by [42] which also developed a similar system without the use of an ML model which aimed at detecting 7 different sitting postures.

4.1.5 Image Sensors

These image-based sensors such as a camera and 3d image sensors typically integrate with a computer vision algorithm which works by capturing visual elements from an image. In the classification of sitting postures, there is normally a digital camera actively positioned directly at the subjects. Furthermore, with the use of image processing libraries such as OpenPose or OpenCV, researchers were able analyse each video frame to determine the sitting posture.

This method is not a very popular option among the research studies found. However, there were a few studies that found that used imaging systems. Mallare et al. in 2017 [60] developed a system utilizing 2 digital cameras, strategically positioned at (front and side) angles in the detection of bad sitting postures. Overall, they were only able to achieve an accuracy of 61.3% using the SVM algorithm. Additionally, Chen et al. in 2019 [52] further improved on this by using an Astra3D Sensor which is a 3D depth camera. With the utilization of the OpenPose library along with CNN for the posture classification, they were able to achieve an overall accuracy of 90%.

4.2 Pressure Sensors Placement Strategy

Across the research studies found, it was seen that are two main approaches being employed in the placement of pressure sensors among smart sensing chairs systems which is the dense sensor configuration and a sparse sensor configuration as describe by Ma et al. [43]. A dense sensor configuration involves the use of a flexible sensor array mat containing multiple pressure sensors units interconnected together. Meanwhile, the sparse sensor configuration goes on the idea of having several individual pressure sensors placed at strategic point around the chair.

4.2.1 Dense Sensor Array

This configuration can also be used with textile pressure sensors. Xu et al, [34] used a textile pressure sensor array along with a dynamic time wrapping based algorithm to classify 7 sitting postures with 85.90 accuracy. Huang et al., 2017 [44] used a 52x44 Piezo-Resistive Sensor Array which was placed on the bottom seating. Using the ANN classifier, they were able to achieve a classification accuracy of 92.2%. Kim et al., 2018 [33] developed a washable fabric-based sensor array. Even after one thousand independent washes, the capacitance reading from textile sensors array had not deteriorated. Kim et al. [45] achieved a 95.30% accuracy using 8x8 pressure array and a CNN classifier to classify 5 sitting postures among children. Similarly, Cai et al. [46] utilized a flexible pressure sensor array (400mm x 400mm) placed on the bottom seat cushion to recognize 6 different sitting postures. Ran et al. [47] installed a 11 × 13 Pressure Sensor Array (IMM00014, I-MOTION) which communicated with a Raspberry PI computer which achieve a 96.22% classification accuracy using a 5-layer ANN classifier as shown in Figure 6a. Ahmad et al. [48] embedded a 16 screen pressure sensor array, also using a raspberry pi for sitting classification which obtained an high accuracy of 99.03% using LightGBM machine learning algorithm shown in Figure 6c. Wang et al. [49] developed 2 sets of interconnected sensor sheets which cover both backrest and the seating cushion of the smart sensing chair seen in Figure 6b. Using the SNN classifier, their proposed system could distinguish 15 different sitting postures with an accuracy of 88.52%, which is among the highest number of postures being classified. Fan et al. [50] also implemented a similar system that analyses the hip pressure, which subsequently achieved an accuracy of 99.82 using CNN. Table 6 below provides the list of studies that used sensor array modules.

A collage of different types of electronics

Description automatically generated

**Figure 6**. Some studies that implemented the use of dense sensor arrays. **(a)** Pressure array cushion n with haptic feedback [47] **(b)** Chair fitted with 2 large pressure sensor array modules placed on the seating cushion [49]; **(c)** Screen printed pressure sensor placed under the seating cushion [48].

**Table 6.** Studies using Dense Sensor Array Configuration

|  |  |  |
| --- | --- | --- |
| **Sensor** | **Accuracy** | **# of Postures** |
| Textile Pressure Sensor Array [34] | 85.90% | 14 |
| 52x44 Piezo-Resistive Sensor Array [44] | 92.20% | 8 |
| Textile Pressure Sensors (Woven Fabric) [33] | - | 7 |
| 8x8 Pressure Mat Sensor [45] | 95.30% | 5 |
| 400mm x 400mm Flexible Array Pressure Sensor [46] | 95.67% | 6 |
| 11 × 13 Pressure Array (IMM00014, I-MOTION) [47] | 97.07% | 7 |
| Screen Printed Pressure sensor units (16 Array) [48] | 99.03% | 4 |
| 2 Pressure Sensors Array (FSR) [49] | 88.52% | 15 |
| 44 × 52 Pressure Sensor Array [50] | 99.82% | 5 |

4.2.2 Sparse Sensor Configuration

This sensor configuration is looks to be a more popular option as more studies implemented this setup compared to its counterpart. The Mutlu et al. in 2007 [51] integrated 19 different FSRs into the seating cushion and used the Simple Logistic Regression ML algorithm to achieve 78% accuracy in classifying 10 different postures. Tsai et al. [52] used 13 pressure sensors to classify 10 sitting postures and was able to achieve an accuracy of 99.10% using the SVM ML algorithm. Aminosharieh Najafi et al. [53] applied 8 sensors (4 on the seating cushion and 4 on the back rest) and used EMN algorithm to classify 8 sitting posture and achieved an accuracy of 91.68%. In addition to this, there was a Desktop Graphical User Interface (GUI) application which displayed the senor reading in real-time. Luna-Perejón et al. [54] added 6 sensors which was placed on the seating cushion and resulted in an 81.5% classification accuracy using SOM (ISOM-SPR) ML algorithm.

**Table 7.** Studies using sparse Sensor Array Configuration

|  |  |  |
| --- | --- | --- |
| **Sensor** | **Accuracy** | **# of Postures** |
| 19 4x4 Pressure sensors (Force Sensing Resistors) [51] | 78% | 10 |
| 6 Flexible Force Sensors (FSR402) [55] | - | 9 |
| 8 Force Sensing Resistors [53] | 91.68% | 8 |
| 6 Pressure Sensors & 6 Infrared Reflective Distance Sensors [56] | 92% | 11 |
| 8 Low resolution matrices of Pressure Sensors [57] | 70% | 8 |
| 12 Pressure Sensor (Force Sensitive Resistor) [58] | 99.47% | 5 |
| 16 Force Sensor [59] | 90.90% | 7 |
| 13 pressure sensors (FSR-406) [52] | 99.10% | 10 |
| 6 Force Sensitive Resistors (FSR) [54] | 81% | 7 |
| 6 FSR Sensors [43] | 89% | 5 |
| 6 Square-Type force Sensing Resistors [60] | - | - |
| 8 Force Sensing Resistors FSR 406 [61] | - | 7 |
| 5 Flex sensors [42] | - | 7 |
| 4 FSR Pressure Sensors [62] | - | 6 |
| 16 Pressure sensors & 2 Ultrasonic sensors [63] | 96% | 15 |
| 9 E-Textile Pressure Sensor [64] | 98.82% | 15 |
| 16 FSR Sensors [65] | 95% | 6 |

4.3 Machine Learning Models

Multiple machine learning algorithms across various studies are being adopted to classify different sitting postures. Two of the most used ML models among research studies were the CNN (Convolutional Neural Networks) [45,50,63,66,67] and ANN (Artificial Neural Networks) [44,47,54,57,60]. Other algorithms being used were KNN (K-Nearest Neighbors) [37,57], Decision Tree [43,61], SVM (Support Vector Machine) [36,52], RF (Random Forest) [59,68], SNN (Spiking Neural Network) [49], SLR (Simple Logistic Regression) [51], Self-Organizing Map [46], Naïve Bayes [19], and Dynamic time Wrapping [34]. On the other hand, there were 7 studies that didn’t employ the use ML models in the classification of sitting postures [32,33,55,60,69,70]. Instead, most of these studies resulted in the implementation of straightforward threshold-based system. In the implementation of this approach, if the sensor data surpassed a specified threshold, a given posture is identified.

To perform a concrete validation on an ML model’s performance and accuracy, most studies result in various methods such as the use of a confusion matrix and performance comparison between different ML models. A confusion matrix is a powerful analytical tool that is used to measure the performance of machine learning algorithms. For binary classification models, there are only 4 possible options within a 2x2 matrix table which is True Positive (TP), True Negative (TN), False Positive (FP), and a False Negative (FN). On the other hand, for multi-class models, the confusion matrix goes beyond a 2x2 matrix, for it becomes a NxN matrix. The N value signifies the number of classes being present [71].

4.4 Integration with (Internet of Things) IoT

Over recent years, IoT has gained in popularity and has become a game changer within certain industries. It was projected that by the year 2030, there would be over 50 billion devices interconnected through IoT [45]. Within the context of smart sensing chair system, Ma et al. [23] highlighted the effectiveness of integrating IoT-based systems into healthcare sensors systems due to its major advantage of being able to seamlessly monitor user’s health data in real-time. The use of IoT systems for remote health monitoring is believed to not only reduce medical costs but could also aid in the early detection of chronic illnesses. Subsequently, this could potentially accelerate the treatment and improve overall life expectancy of an individual.

Now focusing on papers on smart sensing chairs that utilized IoT-based technology, Matuska et al. [55] used an Arduino-based microcontroller which communicated using the MQTT telemetry protocol in order detect 9 different sitting postures. The sensor data was sent in real-time data to a mobile application that alerted a user if an incorrect posture is being detected by signify ‘green”, “orange”, and “red” for standard sitting, bad sitting, and heavy load on backbone respectively. Similarly [69] developed a smart sensing chair which used the Blynk 2.0 platform to stream the sensor data to the web. Other studies such as [62] and [64] similarly used IoT for bad postures detection as well as providing valuable feedback to the end-user.

4.5 User Feedback System

The integration of a feedback system into a smart sensing chair is an integral component of enhancing the user experience. From the end user’s perspective, individuals should be able to receive real-time alerts whenever an improper sitting posture is being detected. It was seen that most studies focus on the classification aspects and leave out the implementation of a feedback platform. So far only 35% (12) of all the studies incorporated a feedback platform that would encourage the user to maintain a correct posture. The implementation of mobile application was seen as the most used platform for alerting a user whenever an improper sitting posture is being detected [46,55,57,63,69]. Another common method was the use of a Desktop application which was done by some studies [49,52,62,66]. Alternatively, instead of implementing an interactive platform such as a mobile or a desktop app, Ran et al. [72], proposed the use of a haptic motor system integrated into the seating which would vibrate whenever an incorrect sitting posture is being detected. To even make the system as unintrusive as possible, [60] looked at using a RGB bulb capable of changing colours whenever an incorrect posture is being detected.

5. Discussion

5.1 Technology

The vast majority of the research studies revealed that the most popular approach to develop a smart sensing chair is to employ the use of pressure sensors. Figure 6 clearly shows that over the years pressure sensors have always been the preferred option in the classification of sitting posture among researchers; out of which, FSR sensors were the preferred option compared to textile pressure sensors.

**Figure 7**. Number of Research Papers published on smart sensing chair technology along with the sensor being used from 2007 to 2023.

In terms of the sensor placement configuration, placing various individual pressure sensors around the chair tends to be preferred method, rather than utilizing dense pressure arrays. So far there was no correlation seen that suggested that one placement strategy that produces higher classification accuracy over the other. However, there are other variables that should be considered such as maintenance and costs. Dense sensor arrays are known to be more costly and harder to manage compared to their counterparts [43]. Reason being in the scenario that one or more of the individual sensing units within the array is faulty, it would be required to replace the entire sensor array further increasing the maintenance costs.

While most studies utilize a singular type of sensor for posture detection, there are a selected few study that involved multiple sensor types into their proposed smart chair system. Jeong and Park [56] utilized 6 pressure sensors (placed on the seating cushion) along with 6 Infrared Reflective Distance Sensors (placed on the back rest). By using the K-Nearest Network (KNN), they were able to classify eleven different sitting postures while achieving an accuracy of 92%. This study highlighted one of the main limitations seen with other smart sensing systems stating that pressure sensors alone are incapable of measuring the spinal trunk angle which another important factor in maintaining a proper sitting posture. Similarly, Cho et al. [63], used 16 pressure sensors place on the sitting cushion along with 2 ultrasonic sensors placed at the neck support region. With this configuration, they were able to achieve 96% accuracy using LBCNet to classify fifteen sitting postures.

5.2 Classification Algorithm

Figure 7 as shown below provides an overview of the machine learning models being utilized and how it correlates the number of postures classified against the overall classification accuracy. Overall, the data suggested that the accuracy of the machine learning model negatively influenced the number of sitting postures being classified. It is evident to see that the more sitting postures that are being classified, the less accuracy its classification accuracy would be. Hence, that is one of the main reasons why most studies on average limit the number of postures to 5-7 positions, which are leaning left, leaning right, leaning backward, upright sitting, and leaning forwards. The study that had the least number of postures classified was by Feng et al. [52] who used RFID tag along with a camera sensor to classify 3 sitting postures (a. Sitting straight, b. Leaning Forward, c. Leaning Backward). On the other hand, Wang et al. [49], Cho et el. [63], Bourahmoune et al. [64] and looked at detecting up to 15 different postures which was the highest number seen among other studies found; achieving an accuracy of 88.52% , 96%, and 98.82% respectively.

**Figure 8.** Comparison of Machine Learning Models: Number of Postures vs Accuracy vs Test Subjects

Additionally, from Figure 8 it was quite interesting to see deep learning models such as CNN and ANN aren’t much better in achieving higher classification accuracies compared to other statistical models. This phenomenon might all come down to the quantity of the dataset being used to train the model. It is known that deep leaning models tend to perform better with large datasets compared to statistical models. Furthermore, this could be theorized that there aren’t enough test subjects being used to train the deep learning models which could further improve its classification accuracy.

5.3 Research Gaps

5.3.1 Lack of User Feedback Evaluation

In examining the current state of this research field, many of the studies predominantly focus on the development of algorithms that would achieve high classification accuracy. Although the pursuit of enhanced algorithmic performance in posture detection is important, there exists a noticeable void in the integration and subsequent evaluation of user feedback methods. Most studies tend to prioritize other aspects such as sensor placement and classification accuracy and leave out the need to perform critical evaluation on user feedback systems for posture correction. As previously discussed, only 11 studies implemented a user feedback system for posture correction; 5 of which used a mobile application. This limited adoption underscores a significant research gap in the assessment of such feedback systems.

With the lack of a comprehensive evaluation being conducted, a few questions can be raised regarding the effectiveness, feasibility, and overall usability from the end user’s perspective when interacting with these systems. Are these systems truly effective in motivating and guiding users towards adopting healthier sitting postures? Performing a critical evaluation on these systems would be beneficial in various aspects. Firstly, it would provide vital information regarding the user experience while interacting with these systems, making it quite easy to find potential gaps that could be further improved upon. Moreover, a detailed examination would elucidate whether user expectations align with the system’s outcomes, thereby facilitating targeted improvements to ensure agreement between user needs and system functionality. Employing methodologies such as user interviews, surveys, and usability testing stands to offer invaluable feedback, paving the way for the refinement of feedback mechanisms within smart sensing chair systems.

5.3.2 Lack of diversity on the training dataset

The quality of the training dataset is very important during the training of machine learningmodel. In the process of model training, test subjects are commonly enlisted to simulatevarious sitting postures over designated periods. On average, the research studies utilize alow number of test subjects, typically around 21 individuals. A sample size this small mightnot be adequate to fully represent the wide postural variances that exist within the widerpopulation. Additionally, there also seems to be a bias towards the test subjects involved inthe data collection, most of which are healthy individuals who are mocking poor sittingpostures.

While this no doubt simplifies the data collection phase for most studies, it fails to accountfor the different challenges involved in the recognition of poor sitting postures amongindividuals that are suffering musculoskeletal conditions. Consequently, the effectiveness ofthe machine learning model might be compromised when applied in real scenario settingsinvolving a much wider demographic.

Addressing this issue requires a lot of effort which involves broadening the dataset by theinclusion of wider demographic ranging from different age groups, body shapes, and healthconditions. Enriching the dataset in this manner would enhance the model**’**s ability toaccurately classify sitting postures among a heterogeneous population, thereby increasingits robustness and applicability in diverse real-world scenarios.

5. Conclusions & Recommendations for Future Research

This paper provides systematic literature review of smart sensing chair systems within the research landscape. It has identified a diverse array of sensors utilized across studies, including Force Sensing Resistors (FSR), textile pressure sensors, load cells, and image sensors, with FSR sensors emerging as the predominant choice among researchers. The strategies for sensor placement predominantly fall into two categories: utilizing a pressure sensor array or distributing individual sensors throughout the chair. Presently, no conclusive evidence suggests a definitive advantage of one strategy over the other in terms of enhancing classification accuracy. However, from a maintenance and cost perspective, the dispersed sensor approach is deemed more favourable. In the area of sitting posture classification, various machine learning models have been employed, with many achieving a high classification accuracy rate of 90%. Despite these successes, a notable gap in the research is the quality of the datasets used for training these models. Predominantly, test subjects are healthy individuals from a narrow demographic, simulating incorrect sitting postures, which raises concerns about the model’s applicability to a broader population, particularly those with musculoskeletal disorders.

Looking ahead, it is important for future research to prioritize the development and rigorous evaluation of user feedback systems aimed at posture correction. Such investigations would significantly contribute to assessing the effectiveness of these systems in real-world settings.

Moreover, there is a compelling case for exploring the integration of various sensor types to enhance the functionality of smart sensing chair systems. While current studies often focus on a single sensor type for posture detection, the integration of multiple sensor types, as demonstrated by Jeong and Park [56], who combined infrared reflective distance sensors with pressure sensors, could offer a more versatile approach to posture classification. Incorporating Inertial Measurement Unit (IMU) sensors could further enable the monitoring of user activity, enriching the data available for posture analysis and correction [43].

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