**Protocol:**

**A Systematic Review of Sleep Posture Recognition Systems: Technologies, Applications, and Challenges**

**Primary Team & Affiliations:** (in no particular order)

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**Declarations**

PL, UW, and TCE declare no conflicts of interest.

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**Introduction**

Sleep posture is prevalent issue, and it may cause pressure injuries (PI) if people sleep for prolonged period in a single posture. PI may result in constant pain, loss of mobility, depression, and even death. The sleep issues are more frequent within the homecare settings [6,7]. Also, some sleep positions and postures are the main reasons of certain illnesses [8]. Individuals who sleep in the decubitus position face a heightened risk of developing subacromial impingement syndrome [9], while those who sleep in the supine position are more prone to experiencing symptoms of sleep paralysis [10]. Similarly, sleeping on the right side increases the likelihood of transient lower esophageal sphincter relaxation, a primary cause of nocturnal gastroesophageal reflux [11]. Additionally, falling out of bed during sleep presents a significant hazard for the elderly, potentially leading to injuries or, in severe cases, fatalities. These risks can be reduced through active and regular monitoring of patients in elderly care facilities. However, detecting and monitoring these conditions can be complex, often requiring additional staff resources, which may increase healthcare costs and add stress for patients. The healthcare community has highlighted the importance of a continuous sleep tracking system to identify patterns and support individuals in setting personalized sleep goals. Clinical evidence suggests that information about the sleep postures can serve as a valuable diagnostic indicator for various chronic diseases and play a supportive role in medical therapies. Therefore, introduction of such systems has the potential to improve the management of sleep disorders, monitor at-risk populations such as the elderly, and offer personalized insights into sleep health. Also, with the integration of Internet of Things (IoT) and cloud-based data analytics, sleep posture monitoring can now be part of a broader, continuous healthcare system that enables real-time diagnosis and longitudinal studies of sleep behaviour.

Researchers have extensively explored aspects related to sleep health resulting in several techniques for identifying the sleep posture. Early studies on sleep postures primarily relied on empirical methods, gathering data through subject interviews. However, recent advancements in IoT technologies and sensing modalities have allowed researchers to more precisely measure sleep postures and patterns. Numerous studies have explored methods to quantify sleep quality and posture [24,25]. In clinical sleep assessments, the current "gold standard" for diagnosing sleep disorders and related issues is polysomnography (PSG) [24]. Numerous smartphone applications [28] and commercial wearable devices [33] have been developed that utilize built-in sensors to track and analyze sleep patterns. Other non-intrusive technologies for detecting sleep posture include methods based on pressure sensors or camera-based visual data analysis [34]. Other approaches used smart bed-type devices in the form of sensors installed on or near the mattress for sleep posture monitoring including RFID, IMU, and WiFi [43, 44, 45]. Recently, pressure sensing entrenched in the mattress has been used extensively [Tang]. There are many studies on posture estimation are based on customized techniques, machine learning, and deep learning.

Considering these technological advancements and the importance of sleep posture in health outcomes, there is a strong motivation to explore the current landscape of sleep posture recognition systems. This review paper aims to provide a comprehensive overview of the current state of sleep posture recognition systems, covering the latest technologies, algorithms, and real-world applications. We will explore the different types of recognition systems, including wearable-based and non-wearable solutions, and discuss their advantages, limitations, and use cases. In addition, we will examine the machine learning techniques used in posture detection, including supervised learning and deep learning models, as well as the datasets and evaluation metrics commonly employed in this domain. Finally, we will discuss the challenges and limitations of existing systems and highlight potential future directions in the field, such as integration with IoT systems, improved privacy features, and personalized sleep monitoring. Furthermore, we aim to identify opportunities for future innovation, particularly in the areas of personalized monitoring, privacy protection, and integration with other health monitoring systems. By synthesizing the existing body of knowledge, this paper seeks to inform researchers, engineers, and healthcare professionals about the advances and challenges in sleep posture recognition, and to identify opportunities for future research and innovation in this rapidly evolving field.

The challenges, rising costs of care and effects of sleep-related issues on the elderly has motivated the researcher to develop systems that could help health practitioners in monitoring patients more efficiently.

Sleep posture recognition has gained significant attention in recent years due to its potential applications in healthcare, ergonomics, and sleep quality analysis. Considering these technological advancements and the importance of sleep posture in health outcomes, there is a strong motivation to explore the current landscape of sleep posture recognition systems (SPRS).

**Background**

Sleep posture plays a critical role in sleep quality, health outcomes, and the diagnosis of various sleep-related disorders. Accurate recognition of sleep postures is essential for improving patient care, particularly in the context of sleep apnea, chronic pain, and musculoskeletal issues. Over the years, various sleep posture recognition systems have been developed, leveraging both wearable and non-wearable technologies, such as pressure sensors, camera-based systems, and machine learning algorithms.

**Aim**

To provide a comprehensive overview of existing sleep posture recognition systems, discussing the underlying technologies, including wearable devices, non-invasive monitoring systems, and the latest advancements in computer vision and deep learning for posture detection.

**Review Questions**

The following research questions are designed to guide the systematic literature review and analysis, focusing on both the technological advancements and practical applications of sleep posture recognition systems:

* RQ1: What are the current methodologies and technologies employed in sleep posture recognition systems, and how do they compare in terms of accuracy, cost, and ease of implementation?
* RQ2: How effective are machine learning algorithms in enhancing the accuracy of sleep posture recognition systems compared to traditional methods?
* RQ3: How do recent advancements in deep learning and computer vision contribute to the development of more effective sleep posture recognition systems?
* RQ4: What are the major challenges and limitations faced by existing sleep posture recognition systems, and what are the potential solutions proposed in recent literature?
* RQ5: implications in both clinical and non-clinical contexts.
* RQ6: Do these technologies measure sleep outcomes, if yes, what kind of outcomes are measured?

**Methods**

**Eligibility Criteria**

* Articles published in English-language are considered.
* The article is concerned with sleep postures recognition.
* The method and classification precision of each posture is stated or reported.
* The same authors mention an identical methodology in two papers with few changes. The study which provided a greater degree of detail.

**Exclusion Criteria:**

The following criteria were used to determine which papers were excluded:

* The article is not concerned with sitting postures.
* The method and classification precision of each posture was not stated or reported.
* If an author used the same methodology in a conference article and a journal article, the conference article was removed to prevent duplication.
* The same authors mention an identical methodology in two papers with few changes. This study provided a greater degree of detail.

**Information Sources**

* PubMed
* IEEE
* ACM
* Scoups
* WOS

**Search String**

To account for variations in methodological terminology, a flexible search string is employed. By combining synonyms for the keywords, a comprehensive search string is developed as follows:

Search String

***PubMed***

All fields:  *"sleep posture" OR "sleep position")  AND ("machine learning" OR "deep learning" OR "neural networks" OR "computer vision" OR "image processing" OR "sensor?based" OR "wearable device" OR "pressure sensor*" OR "IMU" OR "accelerometer" OR "bio?signals" OR "non?contact sensors" OR "infrared imaging" OR "thermal imaging" OR "ultrasound" OR "camera?based systems") AND ("monitor\*" OR "recogni\*" OR "classif\*" OR "detect\*" OR "track\*") AND ("healthcare" OR "hospital\*" OR "care"

***Web of Science Core Collection***

All fields:  *"sleep posture" OR "sleep position")  AND ("machine learning" OR "deep learning" OR "neural networks" OR "computer vision" OR "image processing" OR "sensor?based" OR "wearable device" OR "pressure sensor*" OR "IMU" OR "accelerometer" OR "bio?signals" OR "non?contact sensors" OR "infrared imaging" OR "thermal imaging" OR "ultrasound" OR "camera?based systems") AND ("monitor\*" OR "recogni\*" OR "classif\*" OR "detect\*" OR "track\*") AND ("healthcare" OR "hospital\*" OR "care"

***Scopus***

All fields:  *"sleep posture" OR "sleep position")  AND ("machine learning" OR "deep learning" OR "neural networks" OR "computer vision" OR "image processing" OR "sensor?based" OR "wearable device" OR "pressure sensor*" OR "IMU" OR "accelerometer" OR "bio?signals" OR "non?contact sensors" OR "infrared imaging" OR "thermal imaging" OR "ultrasound" OR "camera?based systems") AND ("monitor\*" OR "recogni\*" OR "classif\*" OR "detect\*" OR "track\*") AND ("healthcare" OR "hospital\*" OR "care"

The returned pool of articles from the Scopus database was further refined using the following filters:

***Excluded subject areas:*** Medicine, ……

***Document type:*** Article

***Language:*** English and German.

**IEEE**

All fields:  *"sleep posture" OR "sleep position")  AND ("machine learning" OR "deep learning" OR "neural networks" OR "computer vision" OR "image processing" OR "sensor?based" OR "wearable device" OR "pressure sensor*" OR "IMU" OR "accelerometer" OR "bio?signals" OR "non?contact sensors" OR "infrared imaging" OR "thermal imaging" OR "ultrasound" OR "camera?based systems") AND ("monitor\*" OR "recogni\*" OR "classif\*" OR "detect\*" OR "track\*") AND ("healthcare" OR "hospital\*" OR "care"

**ACM**

All fields:  *"sleep posture" OR "sleep position")  AND ("machine learning" OR "deep learning" OR "neural networks" OR "computer vision" OR "image processing" OR "sensor?based" OR "wearable device" OR "pressure sensor*" OR "IMU" OR "accelerometer" OR "bio?signals" OR "non?contact sensors" OR "infrared imaging" OR "thermal imaging" OR "ultrasound" OR "camera?based systems") AND ("monitor\*" OR "recogni\*" OR "classif\*" OR "detect\*" OR "track\*") AND ("healthcare" OR "hospital\*" OR "care"

**Search strategy**

* All records

**Data Extraction**

Data extraction will be performed by at least one investigator and reviewed by at least two other investigators. Descriptive data regarding the study, the participants, and the SPRS will be extracted, as will analytical methods. Findings will be extracted in summary form.

**Critical Appraisal**

The quality of the included studies will be assessed using validated tools, such as the Joanna Briggs Institute (JBI) checklist, to evaluate the methodological rigor and reliability of findings. Findings will be categorized based on quality assessments, providing insights into the strength of the evidence base.

**Analysis of the Evidence**

This is a scoping review, and the analysis will primarily focus on descriptive insights rather than in-depth statistical evaluation. It will provide a detailed account of the frequency and distribution of studies involving various technologies and highlight trends, gaps, and areas where research is either abundant or lacking. Included studies will also be categorized based on their quality, determined by the rigor of their methodologies. the review will identify the specific technologies employed, such as wearable sensors, camera-based systems, or pressure-sensing devices, and describe how these have been utilized within the studied populations. By combining these elements, the review will offer a comprehensive overview of the current state of research and its potential implications for future development in the field.

**PRISMA**

This review will be performed in accordance with Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.