IoT PD-RPM Approach: Systematic Literature Review

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Resumo. *This document aims to characterize the state of the art in research fronts related to the remote monitoring of patients undergoing home-based peritoneal dialysis. To conduct this survey, a Systematic Literature Review (SLR) was carried out. The SLR is a research methodology that ensures the reproducibility of the procedures performed in acquiring knowledge about a specific topic [Okoli 2019, Xiao and Watson 2019].*

1. Systematic Literature Review Protocol Adopted

Before defining the SLR protocol, a preliminary literature review was conducted. This unsystematic review aimed to identify studies related to the research topic and assist in defining the keywords and search string to be applied in scientific repositories.

To conduct the SLR, the Parsifal software[1] [García-Peñalvo 2017] was used as a support tool. This free, online tool was essential for this study, as it provided a collaborative workspace where all activities related to the planning (objectives and research questions) and execution phases (search string, keywords and synonyms, inclusion and exclusion criteria) were organized. Additionally, it facilitated the creation of the data extraction form, streamlining the analysis process.

The approach for conducting the SLR, presented in Figure 1, was based on the guidelines and systematic review protocol model proposed by [Kitchenham and Charters 2007]. According to these guidelines, the SLR process comprises several activities, which can be categorized into three main phases: planning, execution, and reporting of the SLR.

1.1. Research Questions

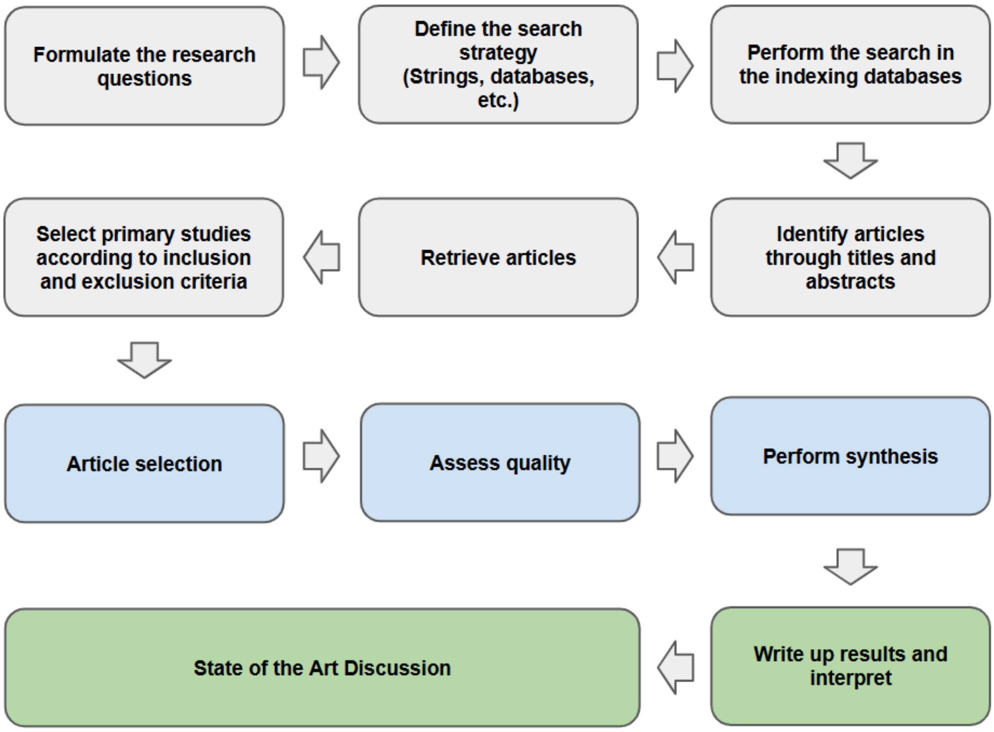
The objective of this systematic review is to analyze the approaches proposed for remote monitoring of patients undergoing peritoneal dialysis over the past five years. The primary focus is to identify the state of the art in home-based peritoneal dialysis patient monitoring.

As the first step in conducting an SLR, it is essential to define the research questions that underpin the study [Petersen et al. 2015]. Thus, the research questions guiding this SLR are presented below:

- RQ1: How are vital signs collected—through the use of sensors and/or manual data entry?
- RQ2: How are the collected data stored? Which platform is used?
- RQ3: How is contextual history considered to provide services and/or relevant information to the user?
- RQ4: Is middleware used in the proposed architecture?

[1]https://parsif.al/

Figura 1. Approach Adopted in the Systematic Literature Review



Source: Prepared by the author, adapted from [Godela 2023]

- RQ5: Is there a provision for issuing alerts based on predefined parameters and/or medical scores?
- RQ6: Are there considerations regarding compliance with the General Data Protection Law (LGPD)?

The strategy for identifying relevant studies included a customized search, utilizing a search string across the selected indexing databases.

The development of the SLR protocol adopted in this thesis followed the PICOC framework (Population, Intervention, Comparison, Outcome, Context), as recommended by [Kitchenham and Charters 2007] and [Petticrew and Roberts 2008].

- Population: Publications that address remote patient monitoring.
- Intervention: The aim of the intervention was to gather evidence regarding the proposed approaches for monitoring patients, particularly in Parkinson's disease (PD).
- Comparison: Comparison between the proposed architectures, as well as the hardware utilized.
- Outcomes: Architectural approaches, techniques, concepts, and middlewares used in the design of applications or systems intended for remote patient monitoring.
- Context: Research related to patient monitoring at home, especially in Parkinson's disease (PD).

In order to identify relevant studies, the search string was applied to six indexing databases: (i) ACM Digital Library; (ii) IEEE Digital Library; (iii) Science Direct; (iv)

Scopus; (v) Springer Link; (vi) Google Scholar. The selection of these databases was based on their importance and relevance in the fields of Computer Science and Nephrology, as well as their coverage of the majority of journals and conference proceedings in this area.

The search string was specified considering the key terms related to patient monitoring, particularly those related to home-based peritoneal dialysis (PD) monitoring. Pilot searches were conducted to iteratively refine the search string. Keywords that did not yield results were excluded. After several iterations, the following search string was finalized for querying keywords, titles, abstracts, and full-text publications: (”remote patient monitoring”OR ”remote peritoneal dialysis monitoring”) AND (”internet of things”OR IoT). Keywords related to the General Data Protection Law (LGPD) were not considered, as they were deemed overly restrictive.

1.2. Inclusion and Exclusion Criteria

To assess the quality of the studies—also referred to as exclusion selection—it is essential to explicitly state in a Systematic Literature Review (SLR) the criteria used to determine which papers will be excluded due to insufficient quality. Additionally, it is necessary to classify the quality of all included papers, depending on the research methodologies they employ [Okoli 2015].

The summarized inclusion and exclusion criteria are presented in Table 1.

Tabela 1. Inclusion and Exclusion Criteria Table

#	**Inclusion Criteria**
1	Primary studies
2	Studies addressing RPM
#	**Exclusion Criteria**
1	Secondary or tertiary studies
2	Duplicate studies
3	Studies published before 2018
4	Studies outside the scope
5	*Short papers* (4 pages or fewer)

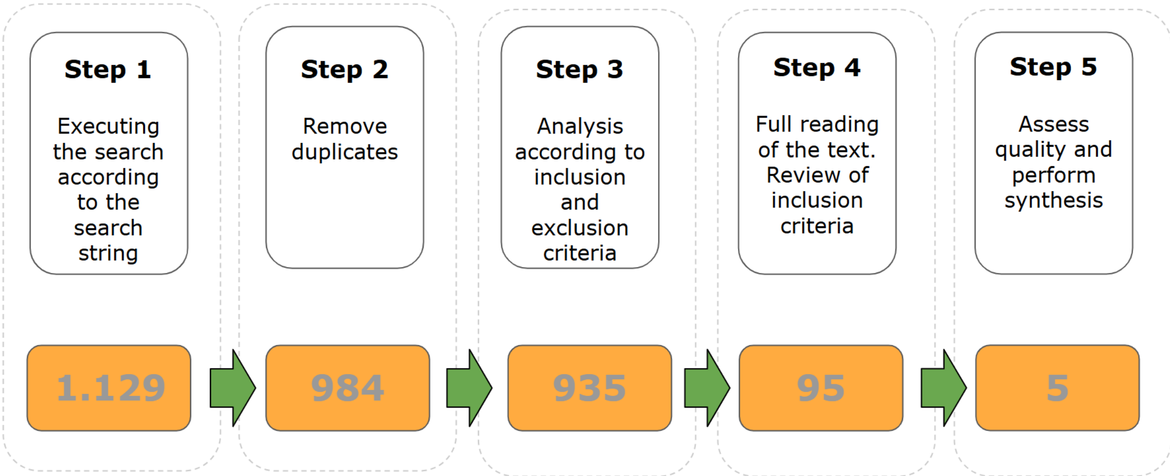
Source: Prepared by the author.

1.3. Study Selection Procedure

The study selection procedure, presented in Figure 2, was divided into five main stages.

In Stage 1, studies were retrieved from databases using the search string. The ACM Digital Library returned 45 results, Scopus 494, Science@Direct 178, Google Scholar 47, Springer Link 231, and IEEE Digital Library 134. The search results (1129 studies) were downloaded, registered, and organized using the Parsifal tool [Lima et al. 2019], except for papers from Google Scholar, which were managed using Zotero [Trinoskey et al. 2009]—a free and open-source browser extension that allows users to collect, manage, store, and cite resources in a single location.

Figura 2. Steps Carried Out in the Systematic Literature Review



Source: Prepared by the author.

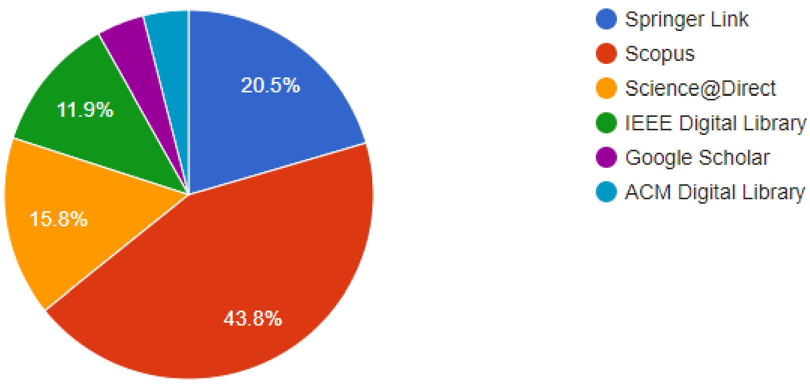
Zotero[2] automatically imports citation information from various sources, including open-access websites, journals, and web-based databases such as Google Scholar.

In Stage 2, duplicate papers were removed. In Stage 3, 840 papers were excluded based on the inclusion and exclusion criteria. In Stage 4, after reading the remaining papers, 95 studies were selected. Finally, in Stage 5, the selected papers underwent a quality assessment, resulting in a final set of 5 papers.

2. Studies Selected in the Systematic Literature Review

Figure 3 provides an overview of the papers retrieved from each indexing database during the systematic review process. It is important to note that the chart in Figure 3 represents the papers obtained in the first stage, prior to the quality assessment.

Figura 3. Papers Retrieved in the Systematic Literature Review by Indexing Database



Source: Prepared by the author.

[2]https://www.zotero.org/https://www.zotero.org/

Table 2 provides an overview of the papers excluded based on each predefined exclusion criterion. As shown, the criterion that excluded the highest number of studies was ”Out-of-scope studies,”resulting in the elimination of 200 papers.

Tabela 2. Total Papers Affected by Exclusion Criteria

Exclusion Criterion	**Papers**
Studies outside the scope	929
Short Papers	8
Secondary or tertiary studies	8
Duplicate studies	145
Studies prior to 2018	33

Source: Prepared by the author.

Below is a characterization of each of the five selected related studies, focusing on their expected applications and the techniques used in their design. The discussion of the selected studies was conducted with the aim of gathering insights to address the research questions considered in this literature review. The objectives of these studies are presented in Subsection 4, along with a critical analysis that draws a parallel to the proposed conception of the IoT PD-RPM.

- **A1: An Internet of Things Application on Continuous Remote Patient Monitoring and Diagnosis [Mia et al. 2021]**
  The objective of this study is to detect medical emergencies and diagnose diseases, enabling authorized individuals to receive notifications on their mobile phones and monitor the patient's condition via a web dashboard or smartphone application. Patient health parameters stored in the database can be queried to predict diseases in advance.
  This research paper presents a non-invasive wearable device that monitors a patient's vital signs in real-time using the Internet of Things (IoT). The proposed device can track body temperature, blood pressure, heart rate, oxygen saturation, blood glucose level, ECG, patient fall detection, and location parameters. Additionally, it includes a breath analyzer unit that measures total volatile organic compounds (VOCs), carbon dioxide, alcohol, hydrogen sulfide, and ammonia levels in the patient's breath. The system utilizes the Blink Cloud platform to store the collected signals. For research purposes, the ThinkSpeak cloud server was used, enabling advanced data analysis in the cloud through MATLAB software.
  The system is designed using an 8-bit microcontroller along with corresponding sensors. Sensor data is transmitted to a web database via a Wi-Fi communication protocol. Additionally, the system features a web control panel and a smartphone application with Role-Based Access Control (RBAC) for remote monitoring of multiple patients. The proposed approach demonstrates an advanced remote patient monitoring and diagnostic system, particularly beneficial for patients with chronic diseases, especially during a pandemic.
  The study concludes that the proposed system optimizes the scheduling of limited medical resources to serve more patients. Moreover, it creates a comprehensive

medical database based on patient health data, placing them under medical surveillance by generating a personal health index. In the future, this system could become a new trend in remote patient monitoring research. It can be integrated with smaller, more sensitive sensors to improve accuracy and reduce device size. A greater number of devices synchronized with a central database could support nationwide digital healthcare services. Therefore, this technology has a significant societal impact in terms of sustainable human development.

- **A2: An IoT-Aware System for Remote Monitoring of Patients with Chronic Heart Failure [Sergi et al. 2023]**
  This study presents the SMART CARE project, which aims to develop an integrated monitoring system composed of hardware and software components to enhance the various stages of managing patients with chronic heart failure (CHF), including prevention, diagnosis, therapy, and follow-up. SMART CARE is an intelligent monitoring system based on IoT technologies that has the potential to transform the management of chronic diseases. It can be integrated with wearable/portable devices and other sensors to track vital signs in real-time. This information can be transmitted to healthcare providers for review, enabling early detection of any changes or potential issues.
  By leveraging new risk calculation tools based on real-world data analysis through Artificial Intelligence (AI), the project aims to enable targeted and early therapeutic interventions that significantly reduce hospital readmissions. An additional innovative feature of the project is its ability to collect data from a low-cost edge node located in the patient's residence. This node can perform an initial assessment of the data, detect deviations from normal behavior, and trigger alerts.
  The anomaly detection algorithm is distributed between the edge node and the cloud. Through this processing, the edge node generates timely notifications or behavioral suggestions that can be sent directly to the patient's mobile device. The same telemedicine platform also sends notifications/alerts to other stakeholders, such as relatives, caregivers, or authorized medical personnel, to facilitate specific actions for the individual patient.
  In the proposed system, data can originate from multiple sources. Potential sources include smart physical or biochemical sensors worn by the patient, wearable/portable devices, and environmental sensors. Additionally, edge devices can perform edge intelligence, meaning they execute AI algorithms locally. This approach reduces the amount of data transmitted to the cloud, as the edge device can filter and analyze data locally, sending only relevant information to the cloud.
  A cloud-based platform is responsible for collecting, storing, and processing patient data. The platform utilizes AI/ML algorithms to analyze the data and identify patterns and anomalies that may indicate changes in the patient's health status, alerting healthcare professionals to take appropriate action.

- **A3: An IoT-Based Duplex Mode Remote Health Monitoring System [Polasi et al. 2023]**
  This study demonstrates the use of Remote Patient Monitoring (RPM), where Wireless Sensor Networks (WSNs) are wirelessly connected using Wireless Body Area Networks (WBANs) to measure significant health parameters such as pa-

tient temperature, heart rate, and blood pressure levels remotely, anytime and anywhere.
Additionally, a MEMS sensor, connected to other sensors, functions as a motion-tracking sensor to monitor the patient's physical condition when they are alone. In cases of unresponsiveness to physical movement, immediate medical assistance is dispatched to the patient's location using a GPS module. By creating an autonomous biomedical monitoring system, these sensors are wirelessly connected to a Wi-Fi module, and the sensor values are then recorded in a medical server through cloud-based wireless communication.
Utilizing LoRa technology, which operates under the Internet of Things (IoT) platform, the system supports a dual-mode functionality, described as a duplex mode. The values are displayed on an LCD screen, and an audible alarm connected to the model acts as an alert system on the other end of the monitoring system. Medical professionals can view and analyze their patients' conditions, providing telemedicine as needed.
Compared to previous studies, this work not only integrates multiple sensors but also incorporates LoRa capabilities. By using long-range communication technology, it covers distances of 15 km or more. The health tracking device is particularly beneficial for patients in rural areas and for individuals who wish to reduce hospital visits.

- **A4: MedPlus - a Cross-Platform Application that Allows Remote Patient Monitoring [Gîştescu et al. 2021]**
  This paper proposes a web application designed to enhance communication between patients and physicians through continuous health monitoring, real-time analysis of patient status, and the reporting of relevant information to a specialist. The proposed solution involves real-time data collection from the Google Fit application[3] installed on the patient's phone, which gathers health data from the phone's standard health app or from connected devices and sensors such as smartwatches, scales, and other peripherals.
  MedPlus is a fully functional web application consisting of a front-end implemented using React.js[4] and a back-end written in Node.js[5]. The proposed patient monitoring system collects health data from the patient's mobile device and analyzes it. Regarding user privacy, the solution employs OAuth[6], an open protocol that enables secure authorization in a simple and standardized manner across web, mobile, and desktop applications.
  Health data analysis is performed every 24 hours on all patient health data collected throughout the day to minimize the false positive rate of reported anomalies. Before a manual review by a physician, the solution integrates an AI-powered service that helps anticipate potential health issues—Microsoft Azure's Anomaly Detector[7]. This service facilitates the seamless incorporation of anomaly detection capabilities, enabling patients and doctors to quickly identify potential problems.

[3] https://developers.google.com/fit/
[4] https://react.dev/
[5] https://nodejs.org/
[6] https://oauth.net/2/
[7] https://learn.microsoft.com/en-us/azure/ai-services/anomaly-detector/

Time-series anomalies can provide valuable insights for critical situations, particularly in the medical field.

The Anomaly Detector identifies whether the collected data contains anomalies and provides a time window in which the anomaly occurred, along with a score indicating its severity compared to other points in the time series. Its anomaly detection processor detects anomalies for each individual time series, while an intelligent alert processor correlates anomalies from different time series and generates a corresponding incident report.

With all collected and analyzed data, a profile is built for each patient. This profile serves as the foundation for physician evaluations, allowing them to provide insights such as diagnoses and treatment recommendations to improve the patient's health condition.

- **A5: Cloud-Based Remote Patient Monitoring System with Abnormality Detection and Alert Notification [Sahu et al. 2022]**

  The paper describes a system capable of measuring various physiological parameters with high accuracy and in accordance with required medical standards. This system enables continuous patient monitoring both locally and remotely through a mobile application, utilizing a cloud-based platform. Additionally, it includes abnormality detection in physiological data and alert notifications.

  A Body Sensor Network (BSN) is employed, consisting of a network of non-invasive sensors used on, around, or inside the body, capable of measuring and transmitting physiological parameters either wirelessly or through wired connections.

  Low-energy Bluetooth (BLE) is used as the interface link between the BSN base station and a mobile gateway. The interface between the gateway and the cloud can be established via Wi-Fi or Ethernet. The gateway can be an Android device, such as a smartphone or tablet. UDP communication, TCP protocol, and WebSocket are utilized to receive data on the cloud server. For real-time Remote Patient Monitoring Systems (RPMS), the patient's physiological parameters are stored in Amazon S3 within Amazon Web Services (AWS)[8]. Amazon REST APIs are used to transmit files from the Android client to the S3 bucket. In case of abnormal events or emergencies, the system can generate an alert notification for both the local user and the remote supervisor.

  The performance analysis of the implemented cloud storage system, in terms of real-time data transmission rates, demonstrates satisfactory system performance. The mobile application developed for Android devices functions effectively for data visualization, analysis, and storage both locally and globally. The feasibility and reliability of the proposed system have been successfully tested and validated. Future work includes data analysis for prognosis, diagnosis, and health condition severity prediction, along with the development of a decision-support system based on acquired data and the patient's medical history.

[8] https://aws.amazon.com/

3. Discussion of Research Questions Considering the Selected Studies in the SLR

In this section, in addition to discussing the Selected Studies identified during the Systematic Literature Review (SLR), the relevance and implications of this discussion in supporting the underlying proposition of this Thesis have also been explored.

As we further analyze the Selected Studies, a critical immersion was conducted into their contributions concerning the research questions that guided the SLR. This approach aimed to provide a broader contextualization of the existing landscape in the field of study of this Thesis, revealing gaps, convergences, and potential directions for the conception of the proposed approach.

RQ1: How Are Vital Signs Collected – Use of Sensors and/or Manual Data Entry?

This functionality becomes feasible due to the environment created by integrated IoT-based systems. The interoperability facilitated by IoT enables smart objects, equipped with internet connectivity and embedded in widely distributed systems, to acquire the ability to efficiently collect, store, and share data.

In light of these definitions, we observe that only two studies provide the possibility of data entry—vital signs—both manually and through sensors.

In the proposed approach, both possibilities were considered, taking into account potential sensor failures. Thus, the patient will have the ability to send data to the medical team even in problematic situations, primarily aiming to ensure the patient's peace of mind. This approach seeks to promote stronger adherence to treatment, providing greater reliability in monitoring and, consequently, enhancing patient safety and satisfaction.

RQ2: How Are the Collected Data Stored? Which Platform Is Used?

All of the selected studies chose to adopt a cloud platform due to its distinguishing characteristics, such as elasticity and high availability.

Several platforms were adopted in the studies analyzed. Study A1 used the Blink Cloud platform, while Study A2, although opting for cloud computing, did not specify the platform used. Study A3 chose to integrate with the Thingspeak platform, Study A4 aligned with the Google Fit infrastructure, and Study A5 relied on the robust Amazon Web Services (AWS) platform. This diversity of choices highlights the variety of available options, each catering to specific needs and reflecting the unique aspects of each research.

In line with this trend, the proposed approach is based on Amazon's cloud platform, which is widely recognized as the oldest and most comprehensive in terms of available services. This strategic selection aims to ensure continuous 24-hour availability, standing out not only for the longevity of the platform but also for its completeness, translating into a robust and reliable infrastructure to support our needs.

RQ3: How Are Context Histories Considered to Provide Relevant Services and/or Information to the User?

With the exception of Study A3, the other selected studies use context histories in one way or another to compare historical series of sensor values or manually entered data.

In the proposed approach, the collected vital signs provide the user with the prerogative to establish context histories, contextualized over time. These histories can be compared with a pattern defined by the user, using Euclidean distances. This technique, which pertains to the calculation of similarity between time-series records, will be employed in the approach discussed in this thesis.

This perspective allows for a meticulous and personalized analysis of the data, offering the user the ability to contextualize and assess variations in vital signs relative to a predefined pattern. This enriches the utility and effectiveness of the system, consequently leading to greater adherence to the treatment, as the medical team will be able to consider the specificities of each peritoneal dialysis (PD) patient. Furthermore, considering interactions with the healthcare team at the Pelotas Nephrology Reference Center, the use of a pattern defined by the healthcare team as a reference for comparisons over time significantly contributes to the interpretability of the indications made by the computational platform.

RQ4: Is Middleware Used in the Architecture of the Proposal?

The incorporation of middleware in IoT architectures offers several significant advantages. Firstly, middleware acts as an intermediate layer that facilitates communication and efficient integration between heterogeneous IoT devices, overcoming challenges related to divergent protocols and diverse technologies.

Furthermore, by providing functionalities such as data management, security, and event coordination, middleware simplifies the development and maintenance of complex IoT applications. Its ability to handle device heterogeneity and offer a consistent interface for developers promotes interoperability, facilitating the creation of robust and scalable solutions.

Additionally, the use of middleware contributes to the flexibility and adaptability of IoT architectures, enabling the integration of new devices and services more swiftly. In summary, the integration of middleware proves crucial for optimizing operational efficiency, promoting interoperability, and simplifying the complexity inherent in Internet of Things architectures.

None of the selected studies use middleware in their architecture. The proposed approach, however, employs the EXEHDA middleware, which provides a robust middleware infrastructure that simplifies the inherent complexity of communication between IoT devices. EXEHDA offers an efficient approach to interoperability, enabling heterogeneous devices to exchange information cohesively and effectively. Moreover, its flexible and scalable architecture adapts to the dynamic demands of IoT environments, providing a conducive environment for the development and implementation of innovative solutions.

RQ5: Is There a Forecast for Alert Issuance Considering Predefined Parameters and/or Medical Scores?

The issuance of alerts in IoT-based healthcare approaches plays a crucial role by providing immediate and precise communication to the medical team. In a context where rapid decision-making can be decisive, the early detection of critical events, variations in vital signs, or other abnormal conditions is vital.

Alert issuance enables the medical team to be immediately notified about emergency situations, facilitating a quick and personalized response. This functionality not only accelerates medical intervention but also contributes to preventing complications, thereby improving the effectiveness of the care provided.

All of the selected studies make use of alerts, as they promote a proactive approach, allowing the medical team to anticipate potential issues and intervene before they escalate.

In the proposed approach, the use of alerts is fundamental to patient adherence. By personalizing the alerts according to the specific needs of each patient, it becomes possible to conduct more precise and individualized monitoring, ensuring that the patient receives feedback from the medical team after each triggered alert.

RQ6: Are There Considerations Regarding Compliance with the LGPD

The General Data Protection Law (LGPD) is a crucial regulatory framework for the protection of personal data in both digital and physical environments. Its importance is underscored by the growing volume of sensitive information being shared and stored by organizations, particularly in the context of rapid global digitalization. By regulating the processing of personal data, the LGPD establishes a set of rights for data subjects and obligations for entities that process this information, promoting greater transparency, security, and control for citizens over their personal information.

For Computer Science, the LGPD presents both challenges and opportunities related to the design of systems, algorithms, and technological solutions that meet compliance requirements. Additionally, the concepts of privacy by design, as incorporated by the LGPD, require developers and software architects to consider privacy as a central principle from the planning and development stages of applications.

The alignment between legal requirements and technical aspects has driven innovations in the field of information security and data protection, encouraging the adoption of new practices and technologies aimed at preserving users' privacy.

None of the selected studies demonstrate concern with adhering to the LGPD's requirements, nor do they incorporate the privacy by design principles outlined by the law in their design. In contrast, the proposed approach, IoT PD-RPM, stands out by including a database auditing module designed to ensure EXEHDA's compliance with the LGPD requirements.

4. Final Considerations

This study provided an in-depth review of the existing literature on remote patient monitoring, with a specific focus on peritoneal dialysis patients, leveraging Internet of Things (IoT) technologies. The systematic literature review culminated in the selection of five relevant studies, whose key features and strategies for remote patient monitoring were examined. These works were compared in order to foster a critical discussion about their characteristics and to identify gaps that could be addressed in future research.

The analysis of the five selected papers revealed several important findings. It was identified that only two studies allowed for manual data input alongside sensor-based data collection. Additionally, all of the studies utilized cloud platforms from different providers, highlighting the diversity of choices in the field. Notably, only one study did not consider Context History Analysis, which is an important aspect of remote patient monitoring. Another key observation was that none of the studies incorporated middleware in their architectures, and none included procedures for ensuring compliance with the General Data Protection Law (LGPD).

Based on these findings, the study emphasized the importance of addressing the identified gaps, such as the inclusion of middleware and the consideration of privacy regulations, which are critical for the development of more robust, secure, and efficient remote monitoring systems. In light of these gaps, Table 3 was developed to present a comparative analysis of the related works and draw a parallel with the proposed approach.

In conclusion, this research contributes to the understanding of current trends in remote patient monitoring, highlighting both achievements and opportunities for further improvement, particularly in terms of interoperability, data privacy, and context-aware analysis. Future work should continue to explore these aspects to enhance the effectiveness of IoT-based healthcare systems.

Tabela 3. Comparative Analysis Between Related Works and the IoT PD-RPM

	Data Entry	Platform	Analysis History	Middleware	Alerts Notifications	Peritoneal Dialysis	Database Audit	LGPD Compliance
A0	Manual and Sensor	Cloud	Yes	Yes	Yes	Yes	Yes	Yes
A1	Sensor	Cloud	Yes	No	Yes	No	No	No
A2	Manual and Sensor	Cloud	Yes	No	Yes	No	No	No
A3	Sensor	Cloud	Yes	No	Yes	No	No	No
A4	Sensor	Cloud	Yes	No	Yes	No	No	No
A5	Manual and Sensor	Cloud	Yes	No	Yes	No	No	No

Source: Prepared by the author.

In this document, dedicated to the analysis of related works with an emphasis on remote patient monitoring, it was observed that they share similarities with IoT PD-RPM approach, even though they are at different levels of technological maturity.

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