Cognitive Decision Support System in IoT Applications

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Abstract: - The value of data from IoT systems can only be realized when intelligence is applied. There is a need to bring intelligence to data using predictive and cognitive analytics by leveraging machine self-learning and the ability to propose solutions with minimal human intervention. A cognitive system is a technology that emulates human-like abilities to process data and learn from it. Cognitive computing technologies, in combination with data produced by connected devices and their actions, allow the design of Cognitive IoT (CIoT). This paper proposes processing complex data sets in CIoT, including structured and unstructured data. With machine learning techniques, cognitive IoT systems gather data from multiple sources and provide decision support with accurate classifications and predictions for various phenomena.

Key-Words: - cognitive computing technologies, Internet of Things (IoT), machine learning, decision support, heterogeneous data, smart livestock

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1 Introduction

More and more devices are continuously connected to the network in homes, offices, factories, and urban transport. Thus, each of them can be monitored, analyzed, and managed over the Internet by various information systems. On the other hand, information systems are becoming distributed, comprising a set of subsystems and services. Such sometimes independent subsystems can be autonomously operated and updated. Enriching information systems with cognitive computing capabilities will improve their functioning and cooperation with users, leading to new properties of the subsystems.

A cognitive system is a technology that tries to simulate human thinking. A Cognitive Internet of Things (IoT) system (CIoT) combines IoT technology with cognitive computing [1] to create intelligent and autonomous systems. Cognitive IoT systems can collect and analyze data from various IoT devices [2], such as sensors, and actuators, analyze the information and construct smart choices [3], [4], [5]. This data can be used to automate data processing tasks, to make classifications and predictions, [6], [7], [8], [9].

CIoT systems find applications in various fields, where decisions can be made via the Internet based on analytics obtained from heterogeneous sensors (Table 1).

Table 1. Potential applications of CIoT systems

Smart Urban Environment	Smart buildings and cities; Smart lighting; Cultural behavior monitoring; Lifestyle monitoring; Public safety; Drone surveillance systems; Portable personal digital assistant
Smart Energy Grid	Smart Energy System; Smart Consumers; Smart Meters
Smart Healthcare	Health monitoring, prediction; Ambient assisted living; Neonatal care
Smart Transportation	Traffic control; Pedestrian detection; Smart routing and parking; Smart and autonomous vehicles
Smart home	Smart home appliances; Smart furniture, thermostats, sockets, locks; Smart home security systems
Smart Farming	Precision Farming; Smart Pest Control, Smart Livestock Management, Smart Greenhouses and Barns, Smart Monitoring of Storage Facilities

The research [4] revealed that “Cognitive computing is about reasoning, learning, explaining, acting, etc.” This technology does not replace human experience but is a tool to widen the ability to understand and predict the world around us, [8]. In this research, we describe how we use machine learning and artificial intelligence throughout the IoT system design to provide decision support for various phenomena. This paper demonstrates data and AI-based decision-making as the main components of the CIoT system. The real-world case study as a CIoT prototype for smart livestock is provided.

2 Components of the Cognitive IoT System

As claimed in [5] the "CIoT architecture consists of sensing components, semantic modeling and reasoning modules, and ML modules".

2.1 IoT Devices

Sensing components such as various sensors, actuators, communication devices, and data processing units provide data [10] for Cognitive IoT. Recently researchers examined intelligent sensing to contribute training datasets towards the CIoT collected by sensors. The rising role of IoT and recent advances in technologies have paved the way for the systemic deployment of IoT-based systems in numerous areas, [11], [12].

2.2 Predictive Analytics

The great progress in the development of various AI algorithms and big data solutions has greatly expanded the field of the use of IoT technologies, [8]. The workflow for predictive analytics is:

- *Data collection:* Sensors on IoT devices collect data about the physical world, such as environmental components (temperature, humidity, etc.), sounds and images, motion, and machine performance.
- *Data processing:* The collected data is processed and stored in a data warehouse or other data storage system.
- *Machine learning:* AI algorithms analyze the data and train machine learning models [13] to make predictions about future events.
- *Decision support:* The predictions made by the machine learning models are presented to users to support decision-making, [14], [15].

3 Decision-making Tasks

Decision-making tasks can be summarized as shown in Table 2.

Table 2. Decision-making tasks of CIoT

Decision-Making Task	Description
Predicting future events	**Analyze** data from IoT devices and predict future events, such as machine failures, traffic congestion, and changes in customer demand. *Decisions about*: how to prevent problems, optimize operations, and improve customer service.
Identifying and responding to potential problems	**Monitor** data from IoT devices and identify potential problems early on. *Decisions about*: scheduling maintenance before the machines fail to avoid costly production downtime.
Optimizing operations	**Identify** ways to optimize operations from IoT data analyses. *Decisions about*: analyzing, adjusting, and improving various processes to achieve maximum efficiency, effectiveness, and quality.

3.1 Models for Decision Making

Decision-making models are frameworks that can help individuals and teams make better decisions. They provide a structured approach to identifying and evaluating options and can help to reduce bias and improve the quality of decision-making. An overview of some of the most common decision-making models is provided in [16]. In addition to the general decision-making models, some specialized models are designed for specific decisions. There is no general single decision-making model that is best for all situations. The choice of model depends on the specific context, goals, and parameters of the decision. For example, there are models for making conclusions about risk, uncertainty, and multiple criteria. A decision support system based on a series of mathematical functions is proposed in [14] and a functional model of decision support is developed in [17].

3.2 AI-based Decision Making

Artificial Intelligence (AI) has achieved increasing "momentum in its application" in many areas with unlimited possibilities, [18]. The integration of artificial intelligence and IoT technologies increases the interconnectedness between systems, [19]. Machine learning (ML) is the main type of AI-based decision-making (Figure 1). Different ML algorithms are widely used for classification and prediction tasks [15], [20], [21].

Data preparation is crucial to the objective's overall success. It is a process of collecting, processing, and analysing data in an established systematic workflow that enables answers and queries to test hypotheses and evaluate results.

Examining raw data sets helps to choose the best approach for conducting analytical research. The main goals of applying Exploratory Data Analysis (EDA) to IoT data are creating a hypothesis about the causes of observed phenomena; assisting in selecting appropriate statistical tools and techniques; building a base for future data collection through research and experimentation; and determining relationships between variables.

Choosing an appropriate algorithm to solve a particular problem depends mainly on the type and size of the data, as well as its quality and quantity after the data preparation stage is completed, [22]. Knowledge of the data and clearly defined objectives are the basis for deciding on the right algorithms, [13].

AI-based decision-making has clear advantages over traditional decision-making methods in terms of speed, accuracy, and consistency. However, some potential drawbacks should also be mentioned. For example, to ensure safety and privacy, new techniques hide some hidden dangers, [23], [24]. The massive amounts of data collected by the system may raise privacy concerns.

It is important to be aware of the potential disadvantages of AI-based decision-making and to take steps to mitigate them.

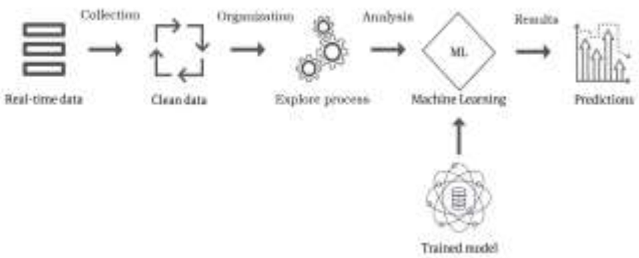

Fig. 1: Machine learning-based CIoT

4 A Cognitive IoT System for Smart Livestock

Smart agriculture is a very modern field, and many companies are investing in building monitoring systems, [25], [26], [27]. At the same time, researchers are working on solutions to overcome current problems and develop new functions to support monitoring processes. They attempt to generate predictions from raw data based on pre-defined algorithms to create meaningful analytical results for real-time decision-making to monitor animal health and reduce the human factor in the breeding process, [28].

Agricultural and farming processes are becoming increasingly data-dependent, [25]. Modern farms have built-in systems that monitor certain parameters such as environmental measurements, caws ID, amount of milk, etc., and the data is presented only in tabular form. There is no analysis, transformation, or visualization of this data. In the developed CIoT system health monitoring is performed by collecting heterogeneous data on the micro and macro climate of the environment through IoT devices, [27]. They are temperature and relative humidity sensors, air velocity sensors, ammonia and carbon dioxide sensors, light sensors, etc. The identification of the animal together with sensors for motion, temperature, humidity, etc. is provided by an IoT device on the cow's neck (Figure 2). In addition, the data on the individual health of each cow is collected, recorded by the veterinarians in a health diary.

The collected data allows the modeling (Figure 3) of processes and phenomena through which early disease prediction (Figure 4), the best time for insemination, animal health status (Figure 5), and other conditions can be achieved, [28]. Various ML algorithms (such as Gaussian Naive Bayes, Decision Tree Classifier, KNN, XGBoost, and Random Forest Classifier) can be applied and compared according to recall, precision, and accuracy metrics. Results vary with each algorithm, [28].

In our work with machine learning, feature selection is a key step, as it involves selecting a subset of significant features from a larger set. The main goal is to improve model performance by reducing complexity, increasing accuracy, and enhancing interpretability. In our feature selection process, we focus on using the Chi-Square test to identify those features that show a strong association with the target variable.

The Chi-Square test is a statistical method for determining a significant association between two categorical variables. To perform this test, we first created a contingency table where we counted the occurrences of each feature within each category of the target variable. This allowed us to calculate the Chi-Square statistic and *p-value* for each feature to evaluate its level of significance. Analytical reports and predictions obtained as the results of processed data with ML algorithms are visualized to support decision-making for farm management. This can improve the quality and quantity of production (Figure 6 and Figure 7), monitor animal health, and reduce the human factor in the breeding process.


Fig. 2: IoT devices on cow necks


Fig. 3: ML models' design


Fig. 4: Data distribution and analysis. The main page of a dashboard – visualization of all columns from multiple datasets

Fig. 5: Result report on cow health

Fig. 6: Analytical report for smart livestock

Fig. 7: Milk quantity prediction

The analyses carried out so far show that the performance of IoT systems is increasingly dependent on the speed of data transmission and therefore convincingly migrates to the Cloud and Cloud Computing, where the user can benefit from the scalability and elasticity of sharing cloud service resources and using remote servers to store, manage, and process data that can be accessed via the Internet on demand, [18], [19].

Properly analyzing the specific services that a Cloud Service Provider can offer specifically for CIoT solutions can significantly increase productivity while remarkably reducing the cost of maintaining it. The risks depend on the cloud service type used by a particular IoT system.

The analysis shows that the same risks can appear to different degrees depending on the specific service, and part of the risks can be distributed between the service provider and its user. The set of individual risks builds its "total risk spectrum" and the most complete list of all possible risks to the user when using cloud services. The analysis of this spectrum is included in the construction of the "sustainability strategies".

Challenges like security and privacy, [29] are crucial in IoT as Cognitive IoT systems collect and process enormous amounts of data. It is important to ensure data is secure and protected from unauthorized access.

A lack of standardization in the cognitive IoT space makes it difficult to develop and deploy CIoT systems. End-users should "consume data from an IoT ecosystem on-demand and autonomously without requiring the support of specialized IT teams" [30] which is important in cases such as smart livestock.

5 Conclusion

The paper demonstrates using data collected from heterogeneous IoT devices in a smart farm. The data was processed with different ML algorithms. The results obtained allow for making decisions about the management of the farm regarding productivity (prediction of estimated amount of milk), and monitoring of the health status of the animals with the aim of timely detection of diseases (classification task).

The developed prototype of the CIoT system for smart animal husbandry is designed to reduce the human factor in the breeding process. Health monitoring is performed by collecting heterogeneous data on the micro and macro climate of the animal environment through IoT devices. Analytical reports and predictions are visualized to support decision-making for farm management.

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Conflict of Interest

The authors have no conflicts of interest to declare.