A User-friendly Cloud-based Multi-agent Information System for Smart Energy-saving

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Abstract

The study focused on leveraging artificial intelligence (AI) for efficient energy conservation in scientific applications. The proposed cloud-based multi-agent system merges various intelligent technologies to swiftly gather high-quality cloud data for effective smart energy-saving. Incorporating case-based reasoning (CBR), big data analysis, and intelligent user interfaces as key functionalities, the system utilized Web services, ontology, open data, and data mining. It expanded on the practical advancements of the multi-agent Dr. What-Info system for information collection. A Web services platform seamlessly gathers cloud interactions among subagents processing energy-saving data. Rigorous performance and operational experiments were conducted to demonstrate the efficiency and effectiveness of the system interface, offering detailed insights into relevant R&D technologies and outcomes.

Keywords: Artificial intelligence, Smart energy-saving, Multi-agent system

1 Introduction

Since 2019, achieving net-zero CO2 emissions by 2050 has emerged as a crucial global objective for all nations. In tandem, the establishment of the Three Percent Club has aimed to propel a 3% annual increase in global energy efficiency [1]. The 2019 International Energy Agency (IEA) report on Energy Efficiency emphasized the pivotal role of information technology in driving energy conservation [2]. For example, the integration of digital technology into a smart energy management system has demonstrated the potential to enhance energy efficiency by 10-30% in both production and operations, simultaneously reducing operational costs. Furthermore, the IEA stresses the importance of involving diverse stakeholders and utilities in this endeavor. It outlines eight dimensions of Readiness essential for effectively managing the advancement of these technologies.

By utilizing AI and big data analysis with government open data, this study aims to seamlessly integrate the eight dimensions of the Energy Efficiency Ready Architecture. This initiative resonates with Taiwan's drive for technological progress, positioning the nation among the world's top ten most digitally advanced governments [3]. Taiwan heavily relies on energy imports to fulfill 98% of its energy needs, resulting in frequent energy shortages [4]. Given these circumstances, the urgency to establish an energy-saving service system becomes increasingly critical. This research aligns with and fulfills the IEA's framework for Readiness for Digital Energy Efficiency, especially considering these pressing factors.

Big data encompasses an immense volume of information too vast for humans to promptly retrieve, manage, process, and interpret. Conventional database systems struggle due to its sheer size, now measured in exabytes for feasible analysis and processing within reasonable timeframes. According to Ylijoki & Porras (academic perspectives) [5] and IBM (industry perspectives), big data embodies four main traits: volume (referring to its sheer quantity), velocity (indicating its rapid generation rate), variety (representing diverse data types and formats), and veracity (highlighting challenges in ensuring accuracy and reliability). However, as suggested by Chen [6], big data isn't solely about terabytes, petabytes, or exabytes but entails a comprehensive and relative dataset that necessitates sorting, analysis, and interpretation to derive meaningful insights and connections between different data points. This study is inspired by this view and employs time-series analysis technology [7] as its fundamental analytical approach.

The proposed system, referred to as WIAS (Web-service based Information Agent System) [8], integrates intelligent technologies within a cloud-based environment. WIAS is designed to facilitate intelligent power management by offering nimble information processing and decision-making services. Moreover, a cloud-based multi-agent system, CEOntoIAS [9], has been developed to streamline information processing, exchange, integration, and analysis among subsystems (as shown in Figure 1). This system aims to enhance the efficiency of agile information operations for smart power management by leveraging OntoIAS's four core functions [10], which encompass information querying, categorization, and presentation. Additionally, it integrates two expanded agent subsystems: OntoDMA, utilizing data mining to reduce processing time, and OntoCBRA, employing case-based reasoning to furnish domain-specific information [7, 11].

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Users and subsystems engage with the system via the Dr. What-Info APP [9, 12], employing a range of input functions. To semantically process queries, the proposed system utilizes Ubi-IA [13], a semantic analysis subsystem driven by domain ontology. It employs CURRL [10-11, 14] in XML format to articulate query content, drawing information from the cloud server system. Operating as the central management hub, the Solution Finder utilizes OntoDMA for proactive real-time predictions of domain information and OntoCBRA for user-centric domain-specific solutions. In cases where these solutions fall short in adequately addressing queries, OntoIAS is activated. It conducts external searches for field-specific information solutions through methods like information search, retrieval, classification, and presentation.

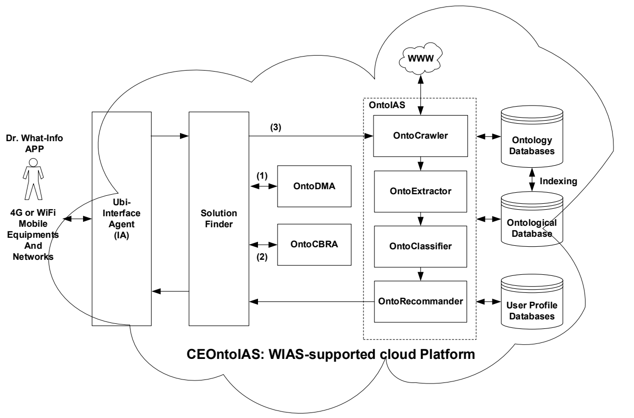
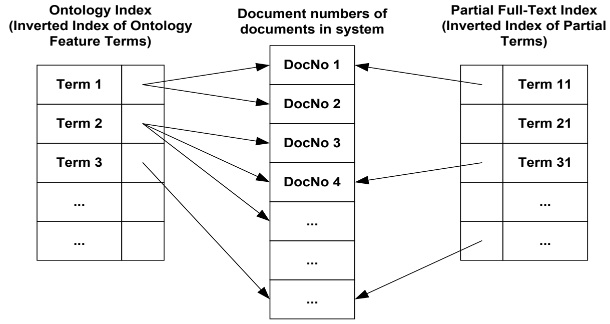


Figure 1. The architecture of the proposed cloud-based multi-agent system

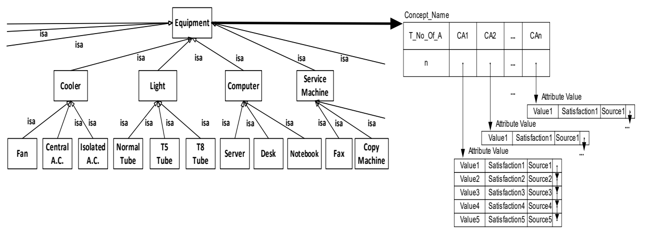
2 Development of Domain Ontology and Related Services

The proposed system leverages Protégé to establish the knowledge base and utilizes its API to facilitate ontology operations [8, 10, 12]. This ontological framework serves to index real information, enabling swift and precise access to relevant data. Figure 2 illustrates the concept of indexing within a smart energy-saving information system. In Figure 2(a), an ontology index organizes related documents. Subsequently, a partial full-text index sifts through documents lacking specific ontological terms, refining the search scope. This two-stage indexing method amalgamates precise domain term meanings from the ontology with real data, effectively pinpointing valuable information. This approach expedites indexing and filtering processes, ensuring rapid and accurate access to essential data (see Figure 2(b) for specifics). Moreover, the system embraces a modular approach to integrate pertinent usage information, catering to diverse scenarios. This modular design enhances accessibility and robustly supports the system's overall functionality, as depicted in Figure 2(c). The study combines WordNet and a Chinese-English bilingual ontology to facilitate bilingual information conversion, establishing connections between language data and conceptual frameworks. This process distinguishes word meanings and correlates these meanings accordingly.

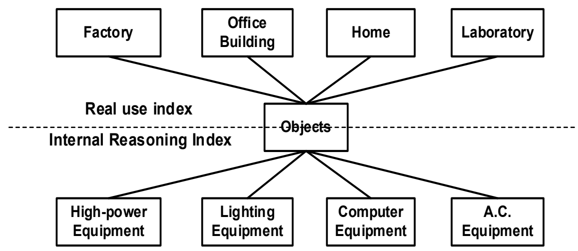
To assess the consistency of ontological concepts, the system employs Jaccard's similarity [10, 12]. Specific analysis rules are defined to capture fundamental ontology concepts [7, 9]. Within these concepts, the system identifies the most indicative domain concept by evaluating its information content value. It then proceeds to map this domain concept onto the WordNet ontology, considering corresponding attributes. The Jaccard similarity measure calculates the concept's consistency within the domain and stores this information for subsequent processing in the relevant attribute. Leveraging the concept ID in WordNet significantly contributes to the system's operations.



(a) Two-stage index architecture



(b) Relationship between ontology structure and collect data



(c) Modular connection and usage

Figure 2. Energy-saving ontology index structure and data relationship

This study develops a specialized event ontology framework specifically tailored for energy-saving events, utilizing a cloud-based Linked Open Data (LOD) database [12-13]. The system's adaptability relies on the existing backend data, functionalities, and the quantity of events. Figure 2 illustrates the relationships between events and the backend data. Finally, the system utilizes GPS data to access pertinent location information from the LOD database.

3 Build Parallel Reduction Mechanism of MapReduce based on the Hadoop Framework

Figure 3 illustrates the proposed parallel reduction mechanism [9, 11], which consists of four key steps: Preprocess: (1) Generates relevant keywords for a website. (2) Map: Utilizes coordinated Jaccard dissimilarity within the domain. (3) Shuffle: Consolidates three sets of keywords for a website. (4) Reduce: Determines the three most similar keywords based on Jaccard dissimilarity and user queries.

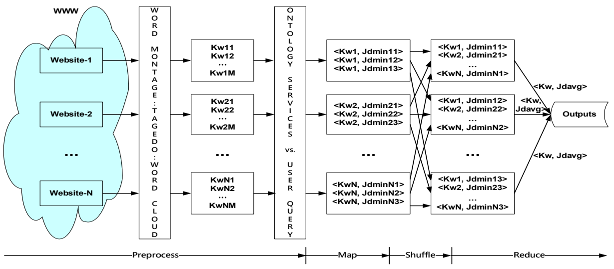


Figure 3. Operations of the proposed parallel reduction

The study uses the Hadoop framework to implement Big Data Analytics. Figure 4 represents the creation of the MapReduce parallel reduction mechanism with the traffic open dataset of the New Taipei City. The system integrates Jaccard dissimilarity calculation for keyword correspondence through domain ontology services. By harnessing big data analysis, this system supports various information services within the WIAS and incorporates well-known data mining algorithms in R.


[{"vdid":"65000V049350","datacollecttime":"2018/08/24 13:04:00","status":"0","vsrid":"1","vsrdir":"0","speed":"61","laneoccupy":"4","carid":"L","volume":"0"},
{"vdid":"65000V049350","datacollecttime":"2018/08/24 13:04:00","status":"0","vsrid":"1","vsrdir":"0","speed":"61","laneoccupy":"4","carid":"S","volume":"12"},
{"vdid":"65000V049350","datacollecttime":"2018/08/24 13:04:00","status":"0","vsrid":"0","vsrdir":"0","speed":"63","laneoccupy":"5","carid":"L","volume":"2"},
{"vdid":"65000V049350","datacollecttime":"2018/08/24 13:04:00","status":"0","vsrid":"0","vsrdir":"0","speed":"63","laneoccupy":"5","carid":"S","volume":"7"},
{"vdid":"65000V049350","datacollecttime":"2018/08/24 13:04:00","status":"0","vsrid":"3","vsrdir":"1","speed":"57","laneoccupy":"8","carid":"L","volume":"0"},
{"vdid":"65000V049350","datacollecttime":"2018/08/24 13:04:00","status":"0","vsrid":"3","vsrdir":"1","speed":"57","laneoccupy":"8","carid":"S","volume":"17"},
{"vdid":"65000V049350","datacollecttime":"2018/08/24 13:04:00","status":"0","vsrid":"2","vsrdir":"1","speed":"42","laneoccupy":"15","carid":"L","volume":"1"},
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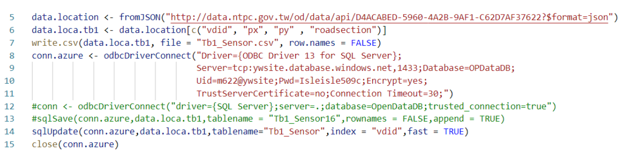
]

(a) Example of dynamic traffic open data



```
data.location <- fromJSON("http://data.ntpc.gov.tw/od/data/api/D4ACABED-5960-4A2B-9AF1-C62D7AF37622?$format=json")
data.loca.tb1 <- data.location[c("vdid", "px", "py" , "roadsection")]
write.csv(data.loca.tb1, file = "Tb1_Sensor.csv", row.names = FALSE)
conn.azure <- odbcDriverConnect("Driver={ODBC Driver 13 for SQL Server};
                                Server=tcp:ywsite.database.windows.net,1433;Database=OPDataDB;
                                Uid=m622@ywsite;Pwd=Isleisle509c;Encrypt=yes;
                                TrustServerCertificate=no;Connection Timeout=30;")
#conn <- odbcDriverConnect("driver={SQL Server};server=.;database=OpenDataDB;trusted_connection=true")
#sqlSave(conn.azure,data.loca.tb1,tablename = "Tb1_Sensor16",rownames = FALSE,append = TRUE)
sqlUpdate(conn.azure,data.loca.tb1,tablename="Tb1_Sensor",index = "vdid",fast = TRUE)
close(conn.azure)
```

(b) Capture dynamic traffic data and build corresponding cloud data

Figure 4. Extract and structure cloud-based data using R from the live traffic data provided by the New Taipei City Government

The major goal of the proposed system is to gather energy-related environmental data, policies for energy planning, and useful toolkits available on the local energy management sharing platform, as shown in Figure 5.

4 WIAS Architecture and OntoIAS Design

Figure 6 presents the hierarchical architecture of the proposed system's web services [10, 14], with SQL IC functioning as the central core service. This architectural framework adopts a modular approach by consolidating intricate database queries and access structures within SQL IC. The cloud data query operations are executed through various functional agents such as IA (interface agent), DM (data mining agent), CBRA (case-based reasoning agent), or Share. The system integrates cloud-based web services to address a wide array of requirements, orchestrated by DB as the consolidation point for these services.

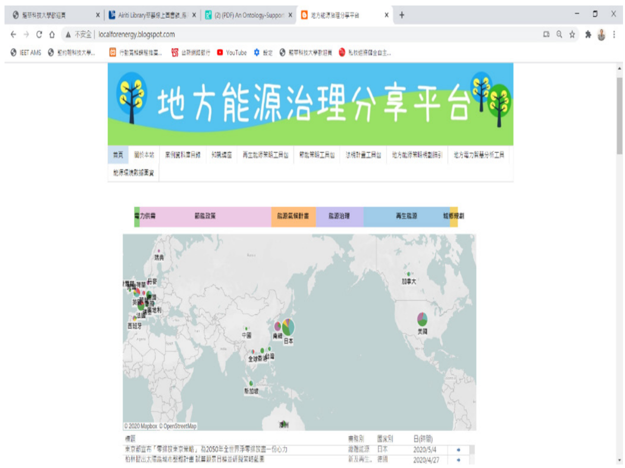
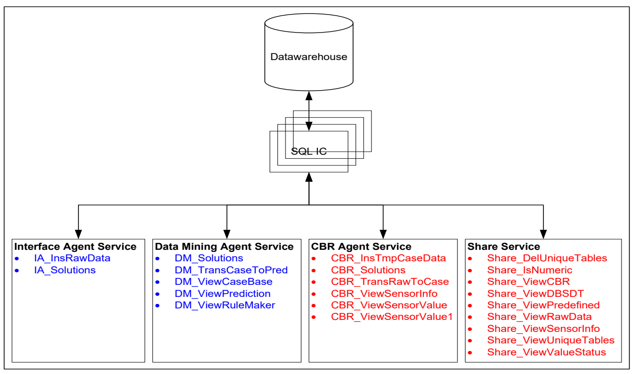
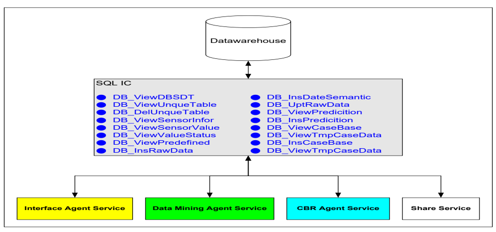


Figure 5. Local energy management sharing platform (http://localforenergy.blogspot.com/)



(a) Web service hierarchy diagram



(b) SQL IC

Figure 6. WIAS system web service hierarchy diagram

Within the Hadoop environment, a range of WIAS-based services complement the MapReduce process alongside the R analysis software, as illustrated in Figure 4 [9, 11]. The WIAS architecture leverages cloud computing to facilitate online data transmission, offering a web service interface for agent access to a shared library. It delineates cloud Web service APIs: UAI includes Connect, Compute, Search, and Storage functionalities, while the R software encompasses Preprocess, Map, Shuffle, and Reduce operations. This approach ensures smooth communication with the cloud database, allowing for easy integration, modification, and updates of essential cloud information functions.

The WIAS architecture, as depicted in Figure 7, functions as a Web service information agent system. It establishes connections between relevant access parameters to retrieve corresponding results from the Raw Data Base. Responses from WIAS are transmitted to the interface agent system through its interface. When the original information aligns with a default response, the Predefined Rule Base is accessed via the Web-Service-Based Interface, delivering the pertinent results to the interface agent system. In scenarios where no predefined answer is available, OntoIAS is activated, employing a parallel decrement mechanism. This process involves utilizing Preprocess, Map, Shuffle, and Reduce operations to search for suitable cloud-based information solutions on the Internet. Domain experts apply rules to create a learning operation aimed at addressing queries.

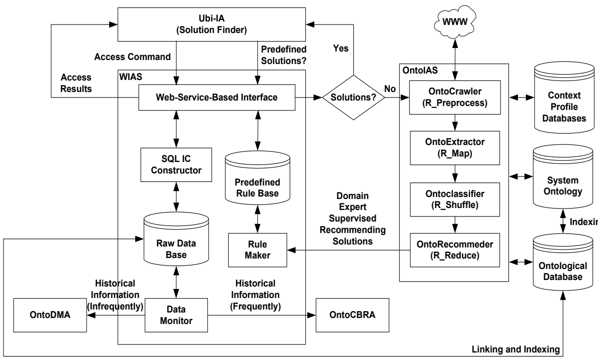


Figure 7. The system architecture of WIAS

Moreover, the Raw Data Base supplies historical data to OntoCBRA via Data Monitor, acting as cloud information for case generation. Occasionally, this historical data triggers OntoDMA to generate cloud-based predictive responses. This method not only allows for the extraction of operational knowledge or rules from relevant cloud information to reduce query processing time but also facilitates learning from cases and operational patterns in cloud information processing, thereby enhancing the system's resilience. It aids in uncovering the optimal cloud information solution within the domain, meeting user requirements and research goals simultaneously.

5 Architecture of Ubi-IA based on WIAS Web services

The Ubi-IA executes three primary functions. First, it receives and transforms queries using the query semantic analyzer (as shown in Table 1). Second, the three-stage intelligent decision assists to make decisions and transmits query responses to the user. Lastly, it displays all processing steps and related data on the cloud information interface for browsing and querying purposes. Figure 8 depicts the three main subsystems: Query Semantic Analyzer, Solution Finder, and Cloud User Interface [12-13, 15-16].

The APP uses EZoAPP for development and Android Studio to create tailored information services for Android devices. It automatically cross-references location data with the server to provide relevant administrative area details and then initiates its operational process. During system operations, the cloud information ontology, crafted by domain experts, matches predefined rules to retrieve valuable information based on query word frequency. It establishes prediction rules for query data. Simultaneously, the information ontology is used to compute similarities between cases supported by the WIAS Web service to initialize CEOntoIAS.

Table 1. Examples of user commands are expressed in CURRL

User commands	CURRL
The maximum rated power of a 2000BTU air conditioner?	Query [Theme = + maximum rated power, aTheme = 2000BTU, tSpace = At (WWW)]
Are there any related web pages?	Command [Theme = +Anymore, tTime = Now, object = Related, oSpace = At (Last-one)]
Capture other energy-saving information except for air-conditioner	ConditionalCommand [Condition [Theme = - air-conditioner, tTime = Now, tSpace = At (WWW)], Command [Theme = + energy-saving, tTime = Now, tSPace = At (WWW)]]

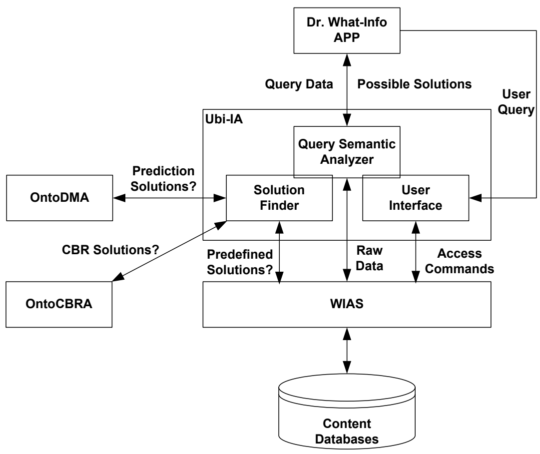
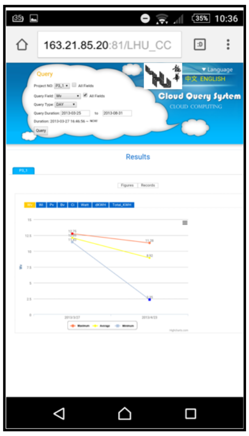


Figure 8. The system architecture of Ubi-IA

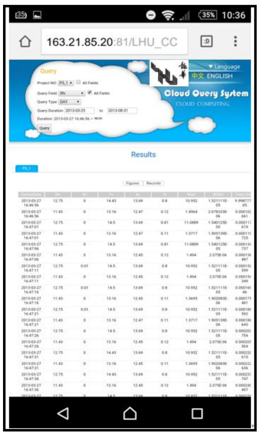
Later, the system consistently manages query frequencies using time series analysis technology. It monitors both high and low-frequency query information. OntoCBRA generates pertinent case details and, employing a two-phase time series prediction, prompts OntoDMA to adjust relevant prediction rules. Leveraging domain ontology, the system significantly enhances the quality of information retrieval for queries. In cases where neither approach yields suitable cloud-based solutions, OntoIAS is employed directly to utilize the parallel decrement mechanism. This mechanism employs intelligent techniques via Hadoop operations to search for suitable solutions, enabling domain experts to incorporate or modify preset rules. This fosters a learning cycle that consistently improves the system's responsiveness to inquiries.

6 System Presentation

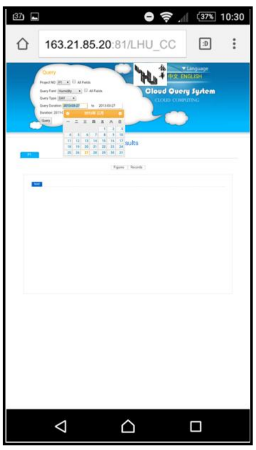
The Dr. What-Info system seamlessly incorporates AI technologies within a framework akin to Hadoop. The utilization of CEOntoIAS as the backend system substantially enhances the quality of cloud-based information, thereby amplifying the effectiveness of mobile inquiries and information sharing. The system's development environment and tools comprise JDK, AppServ, and Microsoft Visual Studio. EzoAPP serves as the platform for implementing the client-side application to support associated information services.



(a) Using graph to show the query results



(b) Example of query results



(c) Inquiry period operation

Figure 9. User interfaces of Ubi-IA

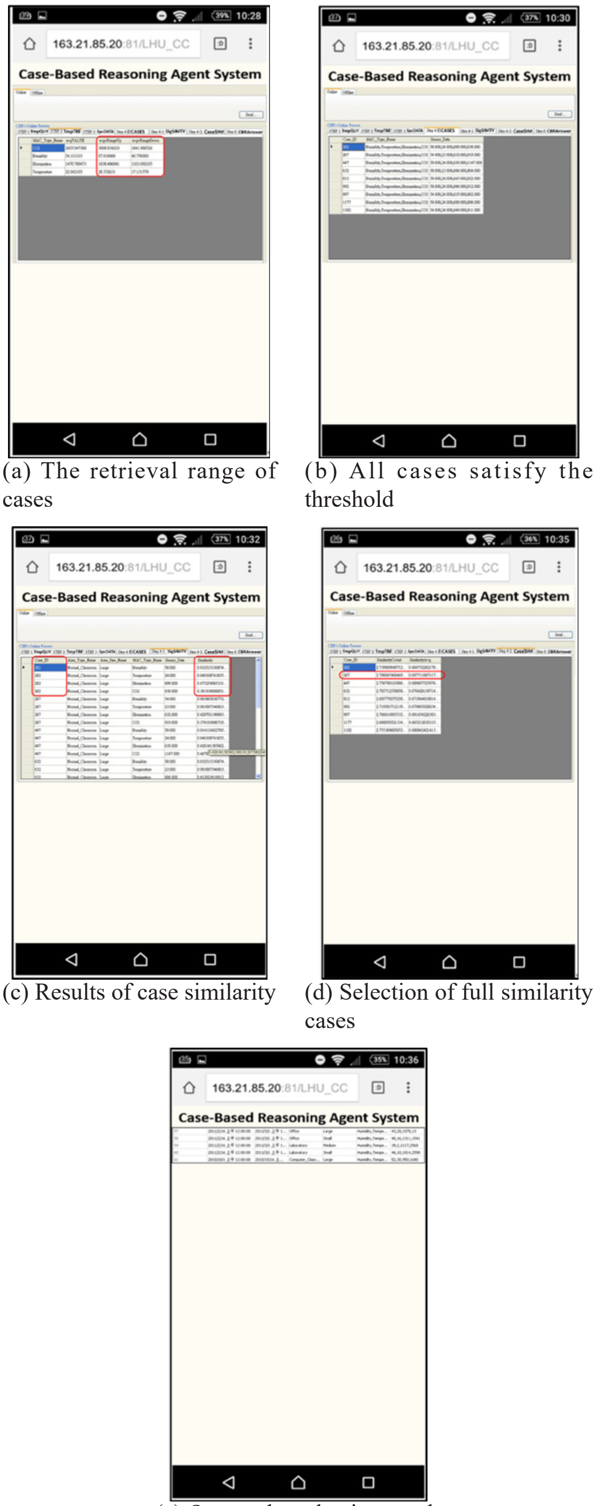
The study prioritizes implementing the proposed system over comparative analysis with similar systems. The Ubi-IA serves three functions: data checking, decision-making, and transmitting results to the monitoring side. All collected data is accessible in cloud environment for user operations, detailed in Figure 9. Different data displays are presented Figure 9(a) showcases query results, while Figure 9(b) exhibits a list of these results. The system interface empowers users to conveniently expand or narrow their data queries using various methods. Additionally, the system can utilize the WIAS service to dynamically display query intervals, allowing users to precisely select their desired inquiry period, demonstrated in Figure 9(c).

During the initial operation of OntoCBRA, the following procedures were performed. Initially, a query involving environmental information was processed but did not translate into a case. Subsequently, the data underwent semantic interpretation to define its content meaning. Finally, Sensor_Data along with its respective operational mode was stored in a case base categorized by sensor types such as Humidity, Temperature, Illumination, and CO2.

In the three-phase smart decision process, OntoDMA managed infrequent or missing query information. In scenarios where OntoDMA encountered difficulty processing the data, OntoCBRA stepped in and used the CBR_InsTmpCaseData web service to store the information in Case_TMP. Activated by the Ubi-IA's solution finder, OntoCBRA initiated the online case application via the CBR_Solutions web service provided by WIAS. During case retrieval operations, the system utilized "avgVALUE". The retrieval scope was determined by calculating "avgVALUE" multiplied by 75% and 125%, resulting in "avgvRangeDown" and "avgvRangeUp," respectively, as illustrated in Figure 10(a). OntoCBRA employed similarity thresholds (75% to 125%), represented by avgvRangeUp and avgvRangeDown, for case retrieval. Figure 10(b) displays all cases that satisfied these thresholds.

The proposed system utilized the ontology database to assess the similarity between cases and the monitored data sequence in Case_TMP, depicted in Figure 10(c). If the data matched "perfectly" with a similarity score of 1 (100%), the system immediately provided that case's answer as the solution for the sequence information value to Ubi-IA, completing the case reuse phase. For data that was "partially similar but not identical," the system proceeded to the case trimming phase, outlined in Figure 10(d). The SimilarityCount column aggregated Similarity values for the same Case_ID, while SimilarityAvg represented the average similarity value. In the case trimming phase, the system selected the Case_ID with the highest similarity as OntoCBRA's output (as demonstrated in Figure 10(e)) and transmitted the result to Ubi-IA for sequential information provision.

OntoDMA functions within two primary segments: an offline phase responsible for automatic prediction rule generation, and an online phase that supports a three-phase intelligent decision-making and processing system. The offline phase involves querying, transferring, and outputting prediction rules using the DM_TransCaseToPred Web service. Conversely, the online aspect of DMA deals with raw energy-saving input data obtained from Ubi-IA, queried through the DM_Solutions Web service provided by WIAS. This operational process is illustrated in Figure 11, where Figure 11(a) showcases DMA information and query results. Figure 11(b) extracts prediction rules from OntoDMA's rule base, while Figure 11(c) retrieves rules that match sensor type and corresponding values. Finally, Figure 11(d) displays the maximum and minimum values corresponding to the sensor type and predicts a query value.

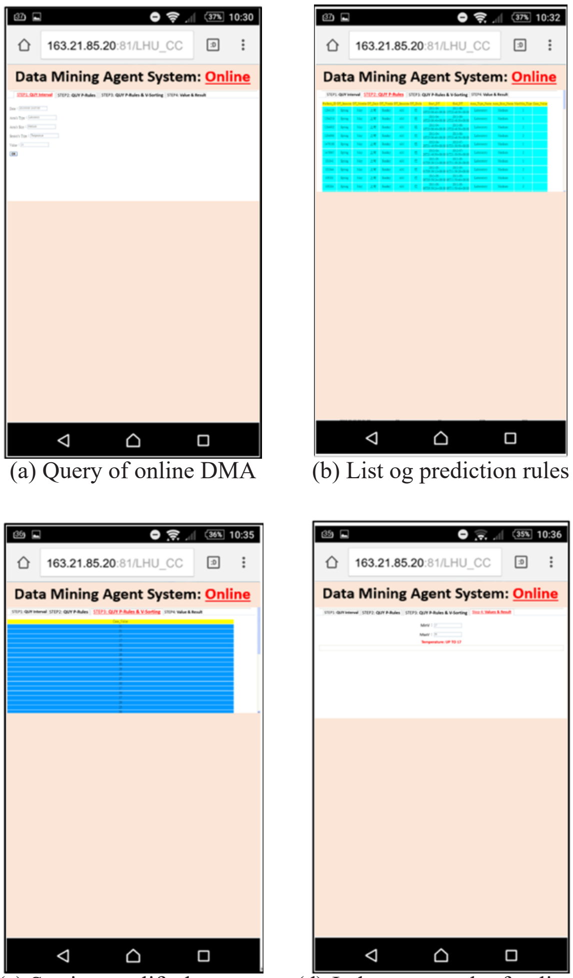


(a) The retrieval range of cases (b) All cases satisfy the threshold

(c) Results of case similarity (d) Selection of full similarity cases

(e) Output the selection result

Figure 10. System presentation of OntoCBRA online operation



(a) Query of online DMA (b) List og prediction rules

(c) Sorting qualified prediction rules (d) Judgment result of online DMA

Figure 11. System presentation of OntoDMA online operation

7 Interface Effectiveness Evaluations

The study involved two groups, the Department of Information Management and the Department of Multimedia and Game Science, each consisting of ten participants. Their feedback was analyzed, and results were deemed valid when achieving a 75% or higher agreement between the groups, indicating a majority consensus.

User satisfaction was assessed based on the system's webpage usability and operational ease. Usability expert Whitney Quesenbery suggests the 5E framework, while Jakob Nielsen proposes ten basic factors of UI design. The proposed system's UI received an overall satisfaction score of 80% for system usability and ease of useThe higher satisfaction score is attributed to the system's intelligent and user-friendly interface design, leading to enhanced user engagement. However, there is potential for improvement in error tolerance based on user expectations.

The design concept of Human-Machine Interface (HMI) in the proposed system adheres to Ha's "Design preference to Importance Ratio (DIR)" [15]. Equation (1) demonstrates the DIR calculation, where a value approaching 1 indicates alignment between the system's design interface and users' crucial needs. Moreover, the "Balancing Index (BI)," described in Equation (2), gauges the perfection of interface settings. A BI value of zero represents a perfectly balanced design, signifying harmony among all HMI components. This emphasizes that the HMI design prioritizes essential user requirements, enhancing the overall user experience while operating the system.

$$DIR_{ijk} = \frac{\dfrac{DP_{ij}}{\sum_{i=1}^{n} DP_{ij}}}{\dfrac{I_{ik}}{\sum_{i=1}^{n} I_{ik}}}. \quad (1)$$

$$BI_{jk} = \frac{\left|\sum_{i=1}^{n} \log_{10} DIR_{ijk}\right|}{n}. \quad (2)$$

where DIR_{ijk} represents the critical design priority ratio between design attribute j and important attribute k of HMI interface component i. DP_{ij} indicates the design priority of HMI interface component i in design attribute j. I_{ik} signifies the design importance of HMI interface component i in attribute k. BI_{jk} stands for the balance index between design attribute j and important attribute k. n denotes the total number of all HMI interface components.

A five-point rating scale method was employed to assess design preference (DPij), ranging from "very good" to "very weak," with values assigned from 5 to 1. Table 2 details the evaluation of HMI concepts in the proposed agent's design interface, along with their corresponding significance determined through the analytic hierarchy process [15-16]. The results of DIR evaluation are presented in Table 3, revealing an average BI (Balance Index) of 0.007673, indicating a near-zero value for optimal balance. Feedback suggests minor adjustments are needed in the proposed system's interface design without significantly impacting system operations. The assessment results confirm that the HMI of the proposed system aligns with design preferences.

Table 2. Assessment of HMI concepts and their importance in the proposed agents

System agent	HMI concepts	Description	Design preference	Informational importance	Annotations
Ubi-IA	QLIST	Query List	5	0.204082	List in text
	FCBOX	Field CheckBox	3	0.265306	CheckBox in text
	QCBOX	Query TextBox	3	0.265306	TextBox in text
	QBOT	Query Bottom	3	0.265306	Bottom in text
CBRA	TTLIST	Text TabList	5	0.263158	TabList in text
	QTBOX	Query TextBox	3	0.368421	TextBox in text
	QBOT	Query Bottom	3	0.368421	Bottom in text
DMA	TTLIST	Text TabList	5	0.263158	TabList in text
	QTBOX	Query TextBox	3	0.368421	TextBox in text
	QBOT	Query Bottom	3	0.368421	Bottom in text

Table 3. Evaluation findings: The average BI for the proposed agents indicates a DIR average of 0.007673

Agent	HMI elements	DIR	BI	Average BI
Ubi-IA	QLIST	1.228055	0.012534	0.007673
	FCBOX	0.939958		
	QCBOX	0.944658		
	QBOT	0.939958		
CBRA	TTLIST	1.270882	0.005242	
	QTBOX	0.903256		
	QBOT	0.903256		
DMA	TTLIST	1.270882	0.005242	
	QTBOX	0.903256		
	QBOT	0.903256		

8 Conclusion

The study proposed a cloud-based multi-agent system focused on promptly accessing valuable energy-saving information from the cloud. Through comprehensive analysis and experiments, several key findings were revealed: (1) The system achieved an overall user satisfaction score of 80%, derived from Quesenbery's 5Es and Nielsen's ratings, indicating positive user feedback. (2) The human-machine interface design aligned with design preferences and reached near-optimal balance, affirmed by DIR and BI verification. (3) The system demonstrated strong performance in the accessibility of information acquisition interfaces. These experiments validate the system's purpose to develop an intelligent mobile information monitor and recommendation multi-agent system, recognized for precision, speed, robustness, universality, and initiative. However, potential areas for improvement include enhancing error tolerance in interface design, optimizing error recognition and recovery, providing helpful documentation, and reducing clicks required for accessing target.

In this study, we developed a CEOntoIAS cloud environment employing Web service technology. This system integrated Taiwan government's open data with UAI-based LOD access tech to establish multi-agent systems for intelligent processing of energy-saving info and decision-making. This integration facilitated the practical application of information agents using ontology tech, along with data mining and case-based reasoning for automatic learning, expanding the system's capabilities. It offers economic benefits and shows promising application prospects, ensuring the continuation of research and development planned by Taiwan's Ministry of Science and Technology.

This research integrates data mining, case-based reasoning, and intelligent environment application technologies, resulting in the development of CEOntoIAS—a multi-agent system supporting intelligent information processing, exchange, and decision-making. The system performs three-phase intelligent decision-making to provide better solutions. Utilizing three-tier address-based, UAI-based LOD access technology, and domain ontology, it intercepts relevant LOD information based on user GPS positions, enhancing the quality and accuracy of intelligent energy-saving consultations. This research makes a unique contribution to related industries and national development, offering an academic perspective on practical technology integration within Taiwan's technical and vocational education system.

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