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Implementation and Challenges of Cognitive IoT

Vaishak Sundaresh[1*], Surekha K Basavanagowda[2], T G Basavaraju[3]

[1] Software Engineer-Faculty, Cranes Software International Ltd, Bengaluru, India
[2] Department of Information Science & Engineering, Acharya Institute of Technology, Bengaluru, India
[3] Department of Computer Science & Engineering, Govt. SKSJT Institute, Bengaluru, India

**Corresponding Author: vaishak.sundaresh@gmail.com, Tel.: +91-98864-34266*

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Abstract— The current research on IOT deals with how the individual things, devices will enable themselves to see hear and smell, it also deals with how these objects can be connected. But for major applications of our day to day life, just connecting the devices is not enough, the objects need to have the capability of learning, thinking and understanding. In other words, the objects need to think like brain of human being. That is adding cognitive feature to the connected devices. In this work, a detailed survey of the present scenario is done and the challenges ahead for cognitive IoT is discussed.

Keywords— Cognitive Internet of Things

I. Introduction

Internet of Things is an interconnection of devices, home appliances and other objects implanted with sensors, actuators and software. The concept of interconnecting all the physical devices for data transmission was theorised during 1990's. But it came into prominence during late 2000's. The initial idea is to give commands to non networking devices which would help in running many applications. Using several devices for transmission of data is good, but transmission of redundant or irrelevant data might lead to resource wastage as well as congestion. It would be proper to transmit only the data which deemed fit based on the application to be used. In such scenario, the physical devices must not only transmit data, but it must also be intelligent in transmitting relevant information. This leads to making a machine think like human brain, in other terms the machine needs to be cognitive. Nowadays the term associated with this concept is called as "Cognitive IoT".

Rest of the paper is organized as follows, Section I consists of introduction to Internet of Things and importance of cognition in IoT. Section II discusses about the work carried out in the field of Cognitive IoT and gives summary of work carried out by different authors. Finally, a framework for Cognitive IoT is presented. Section III gives the conclusion of the work done in the field of Cognitive IoT and the future scope of work that can be explored.

II. REVIEW OF COGNITIVE IOT

The amount of data generated by IoT devices is 2.5 quintillion bytes daily as surveyed in 2008. About 1% of data was able to study among the generated ones. In this context, **Amit Sheth** has discussed the progress path of IoT along data, information, knowledge and wisdom to support more intelligent processing of IoT data.

The paper points out that the advancement of IoT lies in moving

- From single modality of sensors to multimodal sensors and physical-cyber-social data
- From predefined simple events to solutions to unspecified events
- From rule-based maintenance to more prediction driven intervention
- From storing the data for intelligent processing on cloud to "intelligence at the edge"

The paper highlights the challenges in acquisition and processing of IoT data

- Heterogeneity - usage of multiple sensors, devices and textual reports
- Incompleteness - sensor fail or partial coverage due to network limitations
- Uncertainty - Accuracy is an issue in distributed environment like IoT
- Dynamism - rapid state changes

The authors have identified several computing techniques to provide solutions based on the data accumulated through IoT devices. Semantic computing is one among them.

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Semantic computing supports interoperability in sensor - IoT data fusion. Also helps in heterogeneous devices challenge in IoT. A semantic gateway as service helps in translating various IoT messaging protocols like XMPP, CoAP and MQTT. It is also important to have a semantic annotation framework for data produced by the sensors which makes it more meaningful.

Cognitive computing algorithms have the ability to interpret large set of data by learning and comparing patterns in same way as human mind. It also learns from the experiences and performs much better while repeating the task. Even though semantic computing addresses interoperability and integration of heterogenous devices, the complimentary aspects are addressed by cognitive computing such as hypothesising correlations and validating it with evidence. The cognitive IoT has the ability to provide solutions to all the challenges mentioned above.

Perceptual computing provides a capability to ask contextually relevant and personalised questions to gather intelligence from the accumulated data. Context is captured through observations from sensors. Personalization deals with learning preferences and choices by people while interacting with physical world. The usage of both contextual and personalised exploration helps in overcoming dynamism challenge by perceptual computing [1].

Floriano De Rango, Dominico Barletta et al have listed the challenges and upcoming trends to have an IoT architecture between smart devices which consumes less energy for communication. The multi-layer system-oriented architecture developed by Spintel Ltd under iRC is used for analysing power usage of devices in IoT. The above-mentioned architecture also helps to enhance awareness and intelligence in IoT. Here the communication protocol between controlling layer and application layer is analysed for collecting and storing the monitored information from the sensors [2].

Seraphin B. Calo et al discuss about architecture for AI algorithms which uses merits of edge computing and cloud centric computing.

In order to compute and make decisions, a model is built with machine learning algorithms consisting of sample data. These models require high power for processing which is available in the central location. Sensed data is passed to this central location for further processing. Based on the received data, the central location devices build inferences on the models which are devised previously. Here, the latency, network connectivity, data privacy proves to be deterrent.

Alternative approach given by the authors is to build model on cloud and provide the edge with inference task. IoT applications may contain steps based on AI technologies. Here such applications are composed of Cognitive Processing Elements (CPE), it uses AI model to generate the output. NodeRed is a tool for developing applications of IoT which simplifies linking several blocks of code to perform tasks used for proper representation.

Different stages of CPE chains is defined as Data Acquisition, Feature Engineering, Aggregation, Inferencing and reporting. To achieve overall capabilities three phases are described as Discover, Deploy and Operate. Discover phase is to develop the models based on training data. In Deploy phase, selected models are serialized, combined into Docker containers and the repository is shared. The CPE flow is instantiated by Node Red. Operate phase instantiates the Docker container at the edge devices.

The IoT devices large amount of data, the processing should happen near the location in order to increase the efficiency. But processing of many AI and machine learning algorithms requires lot of power which is unavailable in the edge [3].

Shuo Feng et al introduce the concept of Cognitive Dynamic System (CDS) which issues a instructions to setup IoT cognition in a systematic manner. CDS has 5 pillars: perception action cycle, memory, attention, intelligence and language.

In perception-action cycle, the perceptor perceives the environment by operating on the incoming stimuli known as measurements/observables. In response to this, the executor acts on the feedback information from the perceptor.

In memory, it is added to 2 sections of the perception-action cycle called as executive memory and perceptual memory. Perceptual memory allows the perceptor to interpret the observables and categorise the observed features in a proper way. Executive memory observes the actions selected and its successfulness. A CDS model is used which consists of Bayesian filter and model along with reinforcement learning model whose prerogative is to select the feasible action based on the environmental observations (merits/demerits) and pre adaptive subsystem.

Feature extraction is the main feature of the bayesian model. Bayesian filter is a optimal recursive-data processing algorithm for sequential state estimation.
In attention, perception-action cycle is enhanced with perceptual attention and executive attention.

Attention allocates the resources such that the processing power is mainly focussed on gathering information on the strategic critical data. Perceptual attention accounts for the problem of overflow of information whereas executive attention executes a version of least disturbance principle.

Intelligence stage is built on previous 3 pillars and provides the predictive pre adaptive characteristic used in cognitive neuroscience. Intelligence is the most complex and important among all the pillars of CDS. It is based on the information accumulated in earlier stages which allows for optimal decision making in uncertainties of the environment. The reinforcement learning selects best possible action based on the current cycle. The research issue discussed here is in delegating communication between M2M [4].

Cory Henson et al have generated abstractions solely on the qualities discovered. The process of observing qualities and deriving abstraction is called as perception. Abductive logic framework helps in creating abstractions called as Parsimonious Covering Theory (PCT) is presented. PCT utilises background knowledge which is domain oriented to deduce the interpretation of observed qualities. The diagnostic reasoning is divided by PCT into 2 parts: coverage and parsimony.

Coverage criterion determines a set of explanations by taking all the observed qualities into account. Parsimony criterion selects best explanations to bring down the interpretations into reasonable size.
Semantic web (SW) defines a meaning of information on web. Several machine processing languages are defined such as Resource Description Framework (RDF) and Web Ontology Language (OWL). RDF is graph based language used for linking data through named relationships. OWL adds logical foundation to semantic web data. Semantic Sensor Web (SSW) is combination of sensor and semantic web technology. SSW helps in expressing representation, advanced access and formal analysis of sensor resources.

The authors have used SSW including RDF and OWL language. Interpreting PCT into OWL helps in using sensed data in the SSW format by carrying out required abductive deductions with an OWL reasoner [5].

Amit Sheth, Pramod Anantharam, Cory Henson have discussed that Computing for human experience (CHE) and experiential computing makes humans more productive by supporting with information and allows humans to take decision in timely manner which enhances the quality of life. Web has been major source for observing human behaviour pertaining to different situations. Cognitive computing, Semantic computing and perceptual computing plays a major role in collecting and processing of data which would strengthen people's daily life. Semantic Computing and Cognitive Computing personalise raw data by generating hypothesis that bring data nearer to human understandable form. PC collects relevant data from the environment characterised by interpretative and exploratory activities.
In personalised computing, the computers can process and analyse data in a highly contextual and personalised manner at larger scale than human brain. The physical sphere encompasses sensory observations and cyber sphere encompasses all shared data and knowledge on the web. From the collected data, a contextual and personalised data is prepared which can readily be understood by humans.
Semantic Computing represents concepts and their relationships in a semantic network that loosely works like a brain's conceptual interrelationships.

Cognitive Computing interprets observations obtained from SC or raw observations from diverse sources and gives the results to humans. Humans can in turn take necessary actions which acts like additional input to CC. By using background knowledge, CC works with PC to interpret and understand observations.

Perceptual Computing asks different relevant questions and complements SC and CC by proving opportunity to ask next question or derive a hypothesis. PC conducts iterative cycles of exploration and interpretation on the basis of observations relevant to possible hypotheses [6].

The motivation to move towards Cognitive IoT is IoT itself. As IoT is just about connection of things to transmit information, in its original form does not bring convenience and comfortable life to humans.

Qihui Wu et al discuss about Cognitive IoT which allows the objects to be interconnected without human intervention and communication among themselves on context aware perception-action cycle by having technique to learn, adapt to changes, store the learned things in databases. The authors of this paper focus to unite physical world with social world to form intelligent physical-cyber-social(iPCS) system to enable intelligent resource distribution, self-operating network and smart service delivery.

CIoT enriches the IoT by blending human cognitive thinking process to design of the system. CIoT framework presented in the paper acts as a link between social world and physical world forming a iPCS system. This system consists of 4 layers

- Sensing control layer: Direct interaction with physical world where preceptors sense the surroundings and send the feedback to the upper layer.
- Data semantic knowledge layer: Sensed data is analysed to configure semantic knowledge
- Decision-making layer: Based on the intelligence gained from lower layers, the agents plan, select and take appropriate action
- Service evaluation layer: provides on demand service to social networks and performance metrics are designed to evaluate the service and evaluation result is sent to cognition process.

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The CIoT framework includes 5 fundamental cognitive tasks Perception-action cycle: it is the primal cognitive task where input is perception and output produced is an action.

- Massive data analytics, semantic derivation and knowledge discovery, intelligent decision making.
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On demand service provisioning: It supports services like IaaS, PaaS and Sensing as a Service and most importantly Everything as a Service.

Massive Data analytics task is to be performed on large set of data generated by heterogenous interconnected embedded devices. The data is to be analysed, interpreted, understand and use it properly. The algorithms to effectively use massive data is to be developed on basically 4 classes

- Heterogeneous Data Processing: massive data is generated from heterogeneous sensors (cameras, vehicles, drivers/ passengers). In this paper, copula theory is recommended to tackle heterogeneous data processing where due to Sklar Theorem copulas function pairs multivariate joint distributions with marginal distribution functions.
- Nonlinear data processing: Kernel based Learning (KBL) gives a mathematical way to build strong nonlinear variants. The linear data processing is outperformed by non linear data in many practical applications.
- High dimensional data processing: Enormous data generated from images and videos are of high dimensional. KBL discussed previously links original space data into higher dimensional feature space. It can be represented in a compact matrix form. The low rank property in high dimensional data matrix is demonstrated by many practical applications which is helpful in analysing massive data and reduction in dimensionality.

Distributed and parallel data processing: The other classes mentioned perform analysis of massive data in a centralised manner. Alternating Direction method of multipliers (ADMM) is a theoretical structure to perform distributed and parallel data processing.

Semantic derivation and Knowledge Discovery in CIoT task mainly defines semantic derivation whose several key concepts include context, ontology and semantic standardisation. The context is any data required to characterise the entity state. Once data from massive data analytics are organised properly, the analysed data is designed to represent a entity state viewed as context in CIoT. An ontology is a formal, distinct specification of a shared conceptualisation. The major difference from IoT to CIoT lies in knowledge discovery, here the captured data is analysed to come out with proper action. To perform knowledge discovery, several techniques are used like

Association Analysis: Many association types exist in CIoT. Multilevel associations, multidimensional associations and quantitative associations.
Clustering Analysis: It is a process of creating subsets of the analysed data. Each subset is a cluster which are similar yet dissimilar compared to other such clusters.
Outlier analysis: These comes into picture when some of the objects don’t comply into general behaviour. These objects are outliers. Once outliers are discovered they are discarded to keep CIoT environment free from threats.

Intelligent Decision Making for CIoT is another task which performs reasoning, planning and selecting. Selecting is defined as picking an action from the action set based on the requirement. In this paper, multiagency learning is focused as it involves multiple decision makers. The decision makers exchange and interact among their neighbours to come to a decision. In case of large scale CIoT, game theoretic approaches are feasible provided extra efforts to accomplish it. There are some constraints in CIoT while taking decisions on uncertain, dynamic and incomplete information. To deal with these constraints’ optimisation, metrics are to carefully designed. The metrics that can be considered are 1) to maximise expected payoff 2) to minimize outage probability. Performance evaluation metrics in CIoT considered are Profit dimension, Cost dimension [7].

Figure 1 shows the framework of Cognitive IoT. At the hardware level, the data collection is done by the sensors placed in the environment. The data collection depends on the conditions decided previously.
The sensed data is sent to the dat analytics in operations level where the data is arranged, managed and retrieved in a efficient manner. Proper placement of data in its database leads to better performance in timely manner.

In the next stage of operations level, the data is analysed to define the relationship among them. Based on the relationship, knowledge about the information can be gained where redundant data analysis can be eliminated.
In the decision making & action stage, based on the input of knowledge gained about the data sensed in the environment, fruitful decision is taken, and corresponding action is initiated.

At the performance evaluation stage, the action taken in the previous stage is analysed such that if any discrepancies are found, it can be corrected.
The final level in the framework involves Human-Machine Interface where certain questionnaires are given to the user and the answers are adopted into the framework so that any

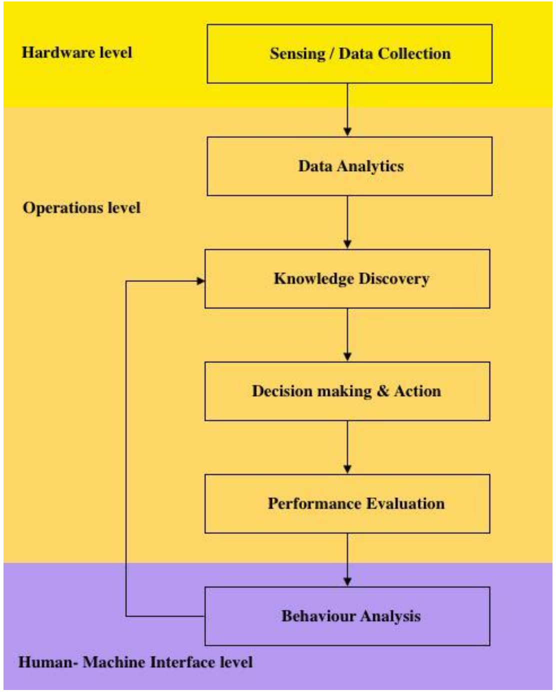

Figure 1: Cognitive IoT Framework

dynamic change in the behaviour can be adopted easily. The result of behaviour analysis is passed back into knowledge discovery stage of operation level so that new knowledge can be gained, and the process continues.

III. Conclusion and Future Scope

Cognitive Internet of Things provides development on Internet of Things concept by not only using devices for communication purpose but as well as intelligence in transmission of relevant information. Based on the information stored and analysed the required action in the environment can be taken. The type of action to be taken is pre-defined but further there is also a scope to improve in decision making which can assess the scenario dynamically and update its course of action.

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Authors Profile

Mr. Vaishak Sundaresh Bachelor of Engineering from Visvesvaraya Technological University, Belagavi in 2009 and Master of Technology from Visvesvaraya Technological University in the year 2011. He is currently working on Machine Learning and IoT technology and working as a Software Engineer – Faculty in Cranes Software International Limited, since December 2018. He was working as an Assistant Professor in the Department of Computer Science and Engineering, Acharya Institute of Technology from July 2012 to December 2018. He is a life member of ISTE since 2015, IAENG since 2017. His main research work focuses on Machine Learning, Internet of Things and Artificial Interlligence. He has 3 survey papers published in reputed journals. He has 6 years of teaching experience and has put his first step in the field of Research recently.

Surekha K.B. is currently working as Associate Professor and Head of ISE at Acharya Institute of Technology,Bangalore. She holds bachelor degree from Kuempu Uniersity,Masters from VTU,Belgaum. She holds a PhD from JNTU,Hyderabad.Her research area are Wireless Sensor Network, IoT and cognitive IoT

T. G. Basavaraju is currently working as professor and head of CSE Department at Government SKSJ Technological Institute, Bangalore. He is a board of studies member in computer science and engineering stream, VTU, belgaum from the year 2013 to 2017. Basavaraju holds a Ph.D. (Engg.) from Jadavpur University, Kolkata in the area of mobile adhoc networks. He obtained his ME in CSE from UVCE, Bangalore University, Bangalore and secured first rank. He has more than 19 years of experience in teaching and industry. He has authored and co-authored five text books in the area of computer networking. One of his co-authored text book on "mobile wireless ad hoc networks: principles, protocols and applications" was published from auerbach publishers (Taylor and Francis group), USA. He has to his credit more than 55 research publications in international journals and conferences

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