SEMANTIC INTEROPERABILITY IN HEALTH DOMAIN USING M3 ONTOLOGY FRAMEWORK

K Parveen[1], G.A. Shah[2], M. Aslam[3], A.A. Malik[4], W. Azeem[5]and M. Asad[6]

[1,2,3] Department of Computer Science, University of Engineering and Technology (UET), Lahore
[4,5]Faculty of Computer Science, Lahore Garrison University, Lahore
[6]Department of Automation, School of Electronics Information and Electrical Engineering, Shanghai Jiao Tong University, Shanghai, China
dr_afatb_malik@lgu.edu.pk

ABSTRACT: In the current era, development in the IOT has led to Web of Things advancements in all fields of life Sciences and medical Science. It's helping people in their lives but still due to the heterogeneity of devices it is facing critical challenges. A smart novel semantic structure is proposed for the implementation of the M3 ontology Web of Things, based on the health domain of triglyceride control system. Triglyceride is related to heart disease. The proposed system shall be helpful to get rid of heterogeneity issue and provide a direct observation of triglyceride patients functioning percentage, required by the physician while examining the patient during appointment. The M3 Ontology is proposed on the Triglyceride control system for the first time. Moreover, during examining the triglyceride, patient's real-time data from sensors and work on the challenge of heterogeneity in such a way that ontology provides a single format for every sensor data.

Keywords: Web of Things; Triglyceride; Interoperability; Resource Description Framework; Ontology

(Received 02.10.2020 Accepted 01.12.2020)

INTRODUCTION

The new sensor technology is evolving day by day and this in return enhancing the Internet of Things (IoT) (Praveen *et al*., 2018). According to (Tabaa *et al*., 2020), research 50 billion smart devices are predicted to be communicated to the Internet through sensors, for different applications like transport systems, smart health systems, management of energy and environment. IoT has transformed daily life applications into smart applications by embedding sensors into general technology. Many efforts have been added for the unification of these IoT devices, one of these efforts is the Web of Things (WoT) Community Group which has initiated the standards by using existing web standards, HTTP, protocols, and Resource Description Framework (RDF) (Zhang *et al*,2016). The characteristic of WoT is to connect anything, anywhere and at any time enables an ultra-large number of devices, things, and networks with a high level of heterogeneity to connect (Korkan, *et al*., 2020). The base of WoT is IoT, in WoT devices or things are interlinked with one another with internet by using web technologies and different standards. The basic purpose of this research is to handle the semantic interoperability in WoT applications, the creation of common semantics in a well-organized way, find a way to produce semantic data with the help of different sources and make a practical, resourceful and well-stranded model.

The interoperability issue arises due to the heterogeneity of the WoT ecosystem. Many solutions have been proposed to overcome interoperability issues in WoT which are discussed in related work. Our main focus would be on heterogeneous information discovery. Many projects cannot do well due to heterogeneity in formats of sensors. Every use-case comes across many sensors and these sensors have their standard that they follow according to their functionality and observations. When these sensors work in collaboration with each other their formats create issues of interoperability. The single system sensors formats must be compliant with each other to overcome ambiguities.

Machine-To-Machine framework is used for semantic annotation and easy interpretation of IoT data to convert IoT data into useful information from a heterogeneous format. It is a standard term that can be used to describe many skills that enable related computers to exchange information and perform various tasks requiring human support. The WoT is an innovative standard that models future Web development by outspreading Web connectivity to physical components such as sensors, RFID tags, and actuators (A. Gyrard, *et al*., 2015). These multi-modal components can operate with extremely widespread and independent features. The RFID is Radio-frequency identification which uses electromagnetic fields to automatically identify and track tags attached to objects; the RFID tag consists of a tiny radio transponder; a radio receiver and transmitter

In this paper, we will explain heterogeneous information discovery through our use-case, which is the 'Triglyceride control system' to overcome the heterogeneity of formats while getting real-time data from sensors in raw form. This article is structured as follows. The paper assesses briefly existing studies on the semantic WoT. It explains Triglyceride, its standard values and recipes as well as Implementation with M3 framework for Triglyceride of health domain is done. Finally, we conclude the paper.

MATERIALS AND METHODS

Semantic WoT: Nowadays WoT is connecting intelligent devices to the web to access data easily. Semantic Web of Things (SWoT) is then a novel research area, the basic objective is to incorporate semantic web technology into WoT for interoperability and to improve the data value produced by connected devices (Shi *et al*, 2010).

Semantic interoperability: Semantic interoperability refers to the meaning of the data or service exchanged among devices. Semantics provide meaning to data and meaningful data can be easily understood by other things and human beings. When a message has been transferred using technical interoperability, decoded, and defined using syntactic interoperability then semantics can make it more useful and understood for other things such as sensors, actuators, human beings. It is easier to understand meaningful data rather than a description of technical traditional protocols (Chindenga *et al*., 2016). Machine interpretation of the content is hard to understand for human beings and hard to process for other machines. Semantics add meaning to technical content and make it more easily understandable for human beings and other things. In an IoT environment, most of the devices have limited resources. Therefore, to understand a technical description may cause difficulties for such devices.

Developments in Semantic Interoperability: W3C has been combined with IoT and WoT data for semantic interoperability (Verdean *et al*, 2017). It has also introduced ontology to represent sensors. Web Ontology Language (OWL) and XML are mostly used to provide meaning to the data within an IoT and WoT environment. Ontology offers a more suitable way to provide the required semantics to the content. Many other data models are used but ontology is more practical and expressive. Ontology provides enriched meanings to the data so that it can be used by other things to make accurate decisions without any human beings intervention which is one of the purposes of IoT (Barnaghi,*et al*.,2011). The main target of IoT and WoT is to represent the things by standard schemas. The W3C focuses on defining standard ontology to represent sensors, data, metadata, and related objects (Barnaghi *et al*., 2012).

There are different semantic IoT applications like naturopathy for multiple datasets. Similarly, Hu *et al* (Li *et al*., 2010) developed an SSEO (Strategic Search Engine Optimization) for semantic indexing purpose, it also helped invent detection with machine processing. In (Santos *et al*.,(2016)), the authors enabled interoperability by Intelligent Personal Assistant (IPA) in the medical field. It functions with the prescribed operating system and cannot handle other OS systems such as iPhone OS or windows phone. It uses semantic web technologies to communicate heterogeneous smart devices. In (Yachir *et al*.,2016), the authors in the agriculture domain proposed a semantic interoperability model by using this proposed model requires further verification for Semantic Interoperability of smart objects.

Jayaraman (Jayaraman *et al*., 2015.) proposed the Open IoT Semantic Interoperability framework for digital agriculture and ontology uses a smart way to collect information, annotation and validation processes. It needs a scalable and intelligent system to enable sensors to communicate semantically and syntactically. Desai *et al*.(Desai *et al*..2015) like Jayaraman used ontology for semantic interoperability. Communication among various protocols such as XMPP, CoAP, and MQTT is facilitated by Semantic Gateway as a Service (SGS) integrated.

XMPP is the open standard for messaging and presence · XMPP powers emerging technologies like IoT, MQTT and CoAP are IoT protocols, but have fundamental differences. MQTT is a many-to-many communication protocol. The CoAP clients and servers both send and receive UDP packets. The basic purpose of an ontology is to provide Semantic Message Interoperability. Although there are various methods for developing semantic interoperability in IoT, there is still a lack of formal approaches to interoperability. Gyrardand Serrano (Gyrard *et al*., 2016) expected SEG methodology for amalgamation and Semantic Interoperability

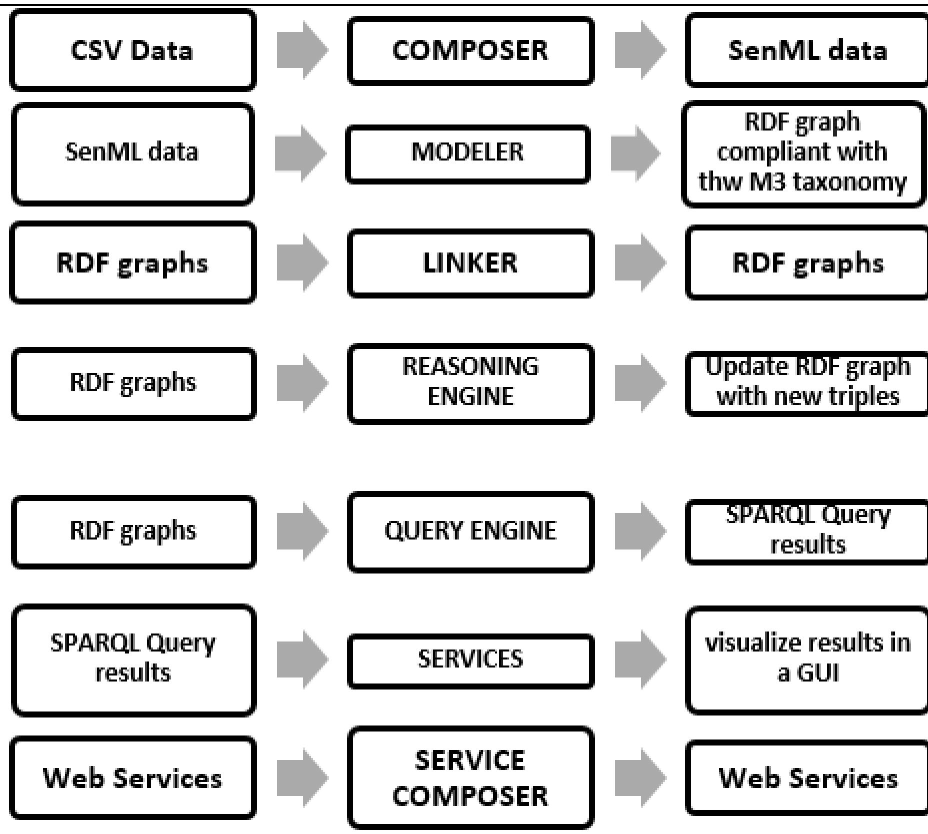

Figure 1: The SEG 3.0 functional framework

It also uses an ontology to put together diverse data collected from different smart things. Figure 1 describes the methodology of SEG 3.0, which consists of the following steps: (1) writing, (2) modeling, (3) linking, (4) reasoning, (5) querying, (6) services, and (7) composition of services. SEG 3.0 is derived from ontology engineering and has the key advantage of combining heterogeneous data obtained from various smart stuff. The research proposed the SEG 3 approach to three separate use cases in the M3 system to assist developers in the design of semantic IoT systems for the Critical EU Smart Cities project and the FIESTA IoT EU Semantic Interoperability project.

To fulfill the standard of achievement of low-power heterogeneous networks, interoperability protocols and standards are needed. To overcome this distance, (Fotouhi *et al*., 2016) defined aspects of various protocol stacks, such as Bluetooth Low Energy, IEEE 802.15.4, ZigBee, 6LoWPAN, and IEEE 802.15.6. They suggested the creation of a standardized protocol stack that communicates with multiple radios and different protocols. Concurrently, irrespective of IP-based or non-IP-based networks. Mingozzi *et al* (Mingozzi *et al*., 2016) introduced a novel universal interface developed to provide context awareness features and demonstrated how these features can be used to automate the search and selection of items via natural language. It is shown that context can be used for services to extract information through semantic reasoning in smart homes. Common standards are driving requirements to enable interoperability between Machine to Machine (M2M) and IoT. In this context, the concept of the ETSI M2M library integrated gateway is proposed by Pereira *et al*. (Pereira *et al*., 2016). Smart Machine-to-Machine (M2M) communications. ETSI is one of the founding partners in one M2M, the global standards initiative that covers requirements.

This is to support the production of IoT applications with reduced development costs. The efficiency is illustrated by testing CPU smartphones, memory consumption and battery life. In (Jayaraman *et al*., 2017), authors have introduced an IoT Cloud data processing architecture that supports semantic interoperability. Google Cloud and Microsoft Azure have been used as a multi-cloud framework for Open IoT architecture. The other IoT definition for factory digitization is suggested in (Shariatzadeh *et al*., 2016). Melie Gyrard (Gyrard *et al*., 2015) have implemented a semantic scheme under which it has been used. The system has been crafted in such a way that it is primarily concerned with data semantics. Enabling the interoperability of equipment. Targeting the question of heterogeneity by including all of it Data is a common standard for the compatibility of all data. As we have been exploring the various problems that are being faced. Acquiring data in IoT, there is different side by side ontologies that genuinely respond to the question of heterogeneity. It also allows inter-data interoperability. Ontologies are a collection of definitions in a topic or domain that shows their properties and the relationship between them. SSN (Semantic Sensor Network). (Jin *et al*., 2018) has a wide variety of sensors. The SSN is the most widely used ontology. IoT Lite (Steinmetz *et al*., 2018) is another ontology used in the explanation of IoT. Extends the SSN structure to provide additional functions. The Architectural Reference Model (ARM) is the only one in the series. An ontology with the least preparation time and higher processing time Complexity, but the observation feature in IoT Lite is not well defined. IoT-A (Shariatzadeh *et al*., 2016) is, in essence, a service focused on ontology, and only Reuses SSN: a feature of the state. It's complicated and difficult to use. An architectural reference model was proposed in IoT-A. IoT-lite seems better, Active as the IoT-A.

In this research paper, M3 Ontology is used. It's a framework introduced for semantic annotation and easy interpretation of IoT data. It converts IoT data into useful information. As, in figure 2 there are multiple data-domains, which can be of health care, environmental, smart city and many others, M3 enables to design such SWoT application, which can be used across domains or even within specific domains.M3 is also an extension of Semantic Sensor network but SSN lacks some attributes of observations like the unit, etc. M3 framework helps developers not only in semantically annotating the data but also provide reasoning on that data that can be derived from various heterogeneous IoT domains. In M3 ontology there are different layers. The first layer is perception layer, in this layer there are many

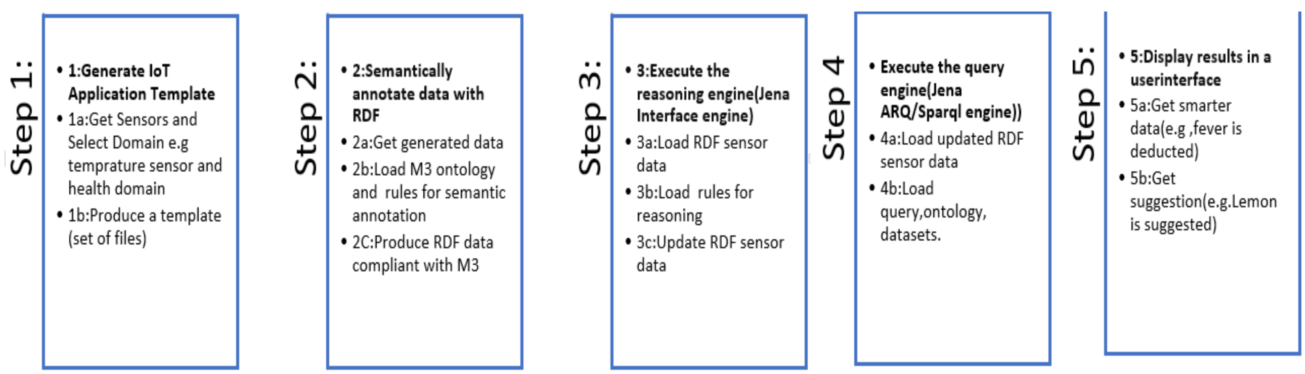

Figure 2: M3 Framework

physical devices like sensors, actuators RFD's, that provide raw data. In the second layer, which is in the Data acquisition layer, sensor data is received from M2M devices, this sensor data converted into structured metadata in the perception layer by using Sensor Markup Language (SenML) which is a lightweight and uniform format to describe the observations of sensors. The metadata consists of information about the unit, name of the sensor, unique ID, type of sensor and timestamps, etc. So, in this layer, data is converted into (RDF/XML) that format compliance with M3 ontology. In the persistence layer, it has a triple store that stores M3 domain ontologies, semantic sensor data, and datasets, SPARQL queries, and rules. Then the knowledge management layer comes, which is responsible for all the domain-specific knowledge, it can later be found, index, design, and reuse and also for combining domain-specific knowledge.

Linked Open Vocabularies are the biggest knowledge-based composed of domain ontologies, data sets, and rules according to semantic web technologies that can be reused later on for cross-domain applications. In the Reasoning layer, it infers rules and new knowledge using the reasoning engines and M3 rules which are extracted from Sensor-based LOR. In the knowledge query layer, it executes SPARQL queries on inferred sensor data. In the Application layer, it acts as a UI, which displays results to the user.

M3 ontology on Triglycerides: In this study, we present a new ontology for high triglyceride patients based on the M3 ontology framework. Our proposed ontology focuses on an automatic solution that decides to get rid of the heterogeneity issue as well as provides direct observation of triglyceride patients with a functioning percentage that will help the doctor right away while examining the patient on appointment.

In this Section, the first discussion topic is triglycerides and then suggest M3 Ontology for triglycerides is introduced on the Triglyceride control system for the first time. Moreover exam-in the triglyceride patient's real-time data from the sensors and work on the challenge of heterogeneity in such a way that the ontology provides a single format for every sensor data

Triglycerides: Triglycerides are a type of saturated cholesterol found in meat, dairy products, and cooking oils. Triglycerides are also produced in the liver. Triglycerides are used for one of two purposes, regardless of whether they originate from the digestion of food or the liver. They can be taken up by cells and tissues and used for energy purposes. Alternatively, they may be processed as fat. The blood becomes high in triglycerides after consuming a meal. It usually takes a couple of hours for triglyceride levels to return to normal. Some people have more trouble clearing the blood of triglycerides after a fatty meal. This is due to a rare genetic disorder called Lipoprotein Lipase Deficiency (LPLD) for a very limited number of individuals. Around 1 in 100 people have a disorder called Common Combined Hyperlipidemia (FCH) where both cholesterol and triglyceride levels are increased. Around 1 in 5000 people have a disorder called Type 3 Hyperlipidemia where both cholesterol and triglycerides are elevated.

Table 1: Triglyceride Values.

Range	Condition
Below 150	Normal value
Above 150 and below 199	Borderline
Above 199 and below 499	High
Above 499	Very High

In table 1, triglycerides value range is shown. If value enhances from 499 then early age heart attacks can cause deaths in patients. So following ontology is proposed to overcome this issue.

M3 Ontology on Triglyceride System

Step1: Generate an IoT application template.
Step1.a: Get Sensor: Triglyceride sensor.
Step1.b: Produce Ontology file of triglyceride in OWL language.
Step2: Semantically annotate data with RDF
Step2.a: Get data generated (measurement type, value, unit, domain, e.g. triglyceride 599mg/dl) (SenML/XML format)
Step2.b: Load M3Ontology and rules for semantic annotation
Step2.c: Produce RDF data compliant with M3
Step3: Execute the reasoning engine (Jena Interface Engine)
Step4: Execute the query engine (Jena ARQ/SPARQL engine)
Step4.a: Load updated RDF sensor data
Step5: Display results in the user interface
Step5.a: Get smarter data e.g. pancreatic pain
Step5.b: Get suggestions e.g. fasting and water drinking

RESULTS AND DISCUSSION

In this section, implementation is done with help of M3 ontology. The scenario is shown in figure 3.

So, for implementing our use-case of Triglyceride control system according to the first step, the device used for checking triglyceride is PRIMA 3in1 which is used for testing cholesterol, triglyceride, and glucose directly at home. We used Prima observations, which will help us directly getting the person's triglyceride condition right away, not only condition but it will also suggest the remedy too. For that, we introduced our m3: Prima with its unit mg/dL in our implementation.

ADD (? measurement m3: has Unit m3: mg/dL) for m3: PRIMA After adding our use-case parameter we need to have some raw data on which our system will do reasoning, for that we used sensor Markup Language.

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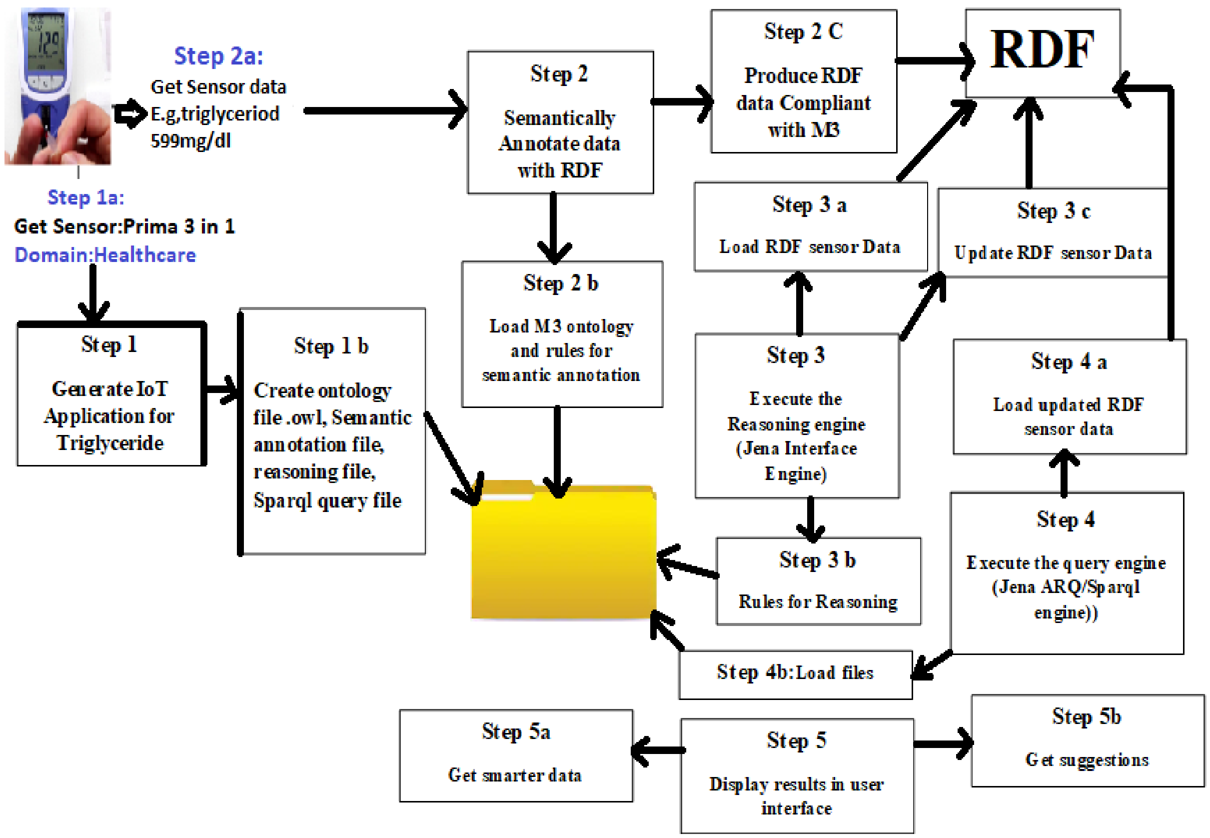

Figure 3: M3 Framework for Triglyceride Control System

Figure 4: Triglyceride Control System Measuring Device

Figure 4 shows data of patients having a name “n” by using device PRIMA whose unit “u” "lPerMin" in time “t” and its value is 129. It is entered manually as [{"n":"urn: dev:ow:PRIMA","u":"lPerMin","t":0, "v":129},] in SenML (Sensor Markup Language), n denotes name, t is for time, u is for unit and v is for value. The M3 system will take this value and gives results based on this value. The readings of device are converted into sensor markup language to transform it into useful information. so for this rules are defined in Linked Open Rules files that contain thousands of rules for many other use-cases too. According to Triglyceride some rules are defined according to health experts and integrate these rules in the XML file as shown below in figure 5. In this file if our value is greater than150 mg/dL then our patient is fine, there is no need for any treatment. But if our value ranges from 200 mg/dL to 500 then our Prima value is quite the worst, you need to take your emergency medicine. And if the value is even less than 500 mg/dl then you need to see your doctor that the critical level for a person. Rules are written in SWRL (Semantic Web Rule Language). As it also gives you suggestions for a Triglyceride person, here is another file that tells you the natural remedies for the disease as shown below.

```
#IF m3: Prima _value LOWER_THAN 150 m3: mg/dL THEN Normal Prima _value
#tested
 [Normal Prima _value:
                         (?measurement rdf:type m3:Prima)
                        (?measurement m3:hasValue ?v)
                        lessThan(?v, 150.0)
                        ->
                        (?measurement rdf:type health-dataset:Normal Prima _value )
]

 #IF m3:PeakFlow GREATER_THAN 200.0 m3: mg/dL AND LOWER_THAN 499.0 m3:
mg/dL THEN high
 [high Prima _value :
                         (?measurement rdf:type m3:Prima)
                        (?measurement m3:hasValue ?v)
                         greaterThan(?v,200.0) lessThan(?v,499.0)
                         ->
                        (?measurement rdf:type health-dataset: high Prima _value)
 ]

#IF m3:PeakFlow GREATER_THAN 500.0 m3: mg/dL THEN  very high
 [very high Prima _value :
                         (?measurement rdf:type m3:Prima)
                        (?measurement m3:hasValue ?v)
                         greaterThan(?v,500.0)
                         ->
                        (?measurement rdf:type health-dataset: very high Prima _value)
 ]
```

Figure 5: XML FILE

Case 1: Normal value (triglyceride value 150) then Normal Healthy diet.

Case 2: Borderline (triglyceride value above 150and below 199) then Normal Diet without oil and sugar.

Case 3: High (triglyceride value above 199and below 499) then Diet without oil and sugar and food that contain plant sterols and stanols, which block the body from absorbing cholesterol, Like Oats, Barley and other whole grains, Beans, Eggplant, okra, Nuts, Apples, strawberries, citrus fruits.

Case 4: Very high, highest risk (triglyceride value above 499) then 6-hour fasting and do running or cycling to burn calories, after 6-hour drink water with some salt and a very small portion of foods like Oats, Barley and other whole grains, Beans, Eggplant, okra, Nuts, Apples, strawberries, citrus fruits to just give a feeling to the patient that he/she is eating something remember a very small portion of food.

```
<naturopathy:Food rdf:about="cinnamon">
<rdfs:label xml:lang="fr"></rdfs:label>
<rdfs:label xml:lang="en">cinnamon</rdfs:label>
<rdf:type rdf:resource="&naturopathy;Fruit"/>
 <rdf:type rdf:resource="&food;Lemon"/> <rdfs:comment xml:lang="en">
Honey is used as a mixture with many natural products such as lemon, clover,
cinnamon and water for treatments of various ailments and other health
disorders.</rdfs:comment> <dc:description xml:lang="en">Honey is used as
a mixture with many natural products such as lemon, clover, cinnamon and
water for treatments of various ailments and other health
disorders.</dc:description>  </naturopathy:Food>
```

Figure 6: RECIPES FILE.

Figure 6, suggests natural remedy foods for worst and normal Prima values. As in case of critical value you need to see your doctor first. It also provides a research paper for a better understanding of how it is better for patients. Therefore, suggestions are deduced based on our SPARQL query, which extracts our results based on the condition which is shown in figure 7.


```
<rdf:Description rdf:about="http://sensormeasurement.appspot.com/m3#Measurement1">
 <m3:hasUnit rdf:datatype="http://www.w3.org/2001/XMLSchema#string">mg/Dl</m3:hasUnit> <m3:hasDateTimeValue
rdf:datatype="http://www.w3.org/2001/XMLSchema#dateTime">0.0</m3:hasDateTimeV alue> <m3:hasValue
rdf:datatype="http://www.w3.org/2001/XMLSchema#decimal">221.0</m3:hasValue> <m3:hasName
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">Prima</m3:hasName> </rdf:Description>
<?xml version="1.0"?> <sparql xmlns="http://www.w3.org/2005/sparql-results#">
 <head>
 <variable name="name"/> <variable name="value"/>
<variable name="unit"/>
<variable name="inferType"/>
 <variable name="deduce"/>
 <variable name="suggest"/>
 <variable name="suggest_comment"/>
</head>
 <results>
 <binding    name="name"> <literal datatype="http://www.w3.org/2001/XMLSchema#string">PRIMA</literal>
</binding>
 <binding    name="value">
<literal datatype="http://www.w3.org/2001//XMLSchema#decimal">221.0</literal> </binding>
<binding    name="unit">
<literal datatype="http://www.w3.org/2001/XMLSchema#string">lPerMin</literal> </binding>
<binding name="inferType">
<literal xml:lang="en">PRIMA</literal>
 </binding>
<binding name="deduce"><literal xml:lang="en">high triglycerides</literal>
 </binding>
<binding name="suggest">
<literal xml:lang="en">oil free and sugar free foods</literal>
</binding>
 <binding name="suggest_comment">
<literal xml:lang="en"> oil free and sugar free foods for triglyceriod (Review) by  Annette Hauenschild Reinhard G. Bretzel
Henning Schnell-Kretschmer Hans-Ulrich Kloer Philip D. Hardt Nils Ewald  in the paper “Successful Treatment of Severe
Hypertriglyceridemia with a Formula Diet Rich in Omega–3 Fatty Acids and Medium-Chain Triglycerides”. It has been
suggested that sugar and oil free foods may reduce high triglyceriod symptoms </literal> </binding> </result> </results>
</sparql>
```


Figure 7: SPARQL QUERY

	PATIENT 1	PATIENT 2	PATIENT 3
T1-VALUE	**1112**	**500**	**525**
T2-VALUE	**712**	**400**	**812**
T3-VALUE	**449**	**220**	**190**

Figure 8: Patients Triglyceride Values

In this table, there is data of 3 patients along with their three appointments readings of PRIMA after regular intervals are shown in figure 8. We can easily see the signs of improvements in patients.

In figure 9 graph, one can know about his/her triglyceride condition easily. This will further help them to take care of themself in a much better way as triglyceride can only be controlled but can’t be fully cured. The major focus in this research paper is on heterogeneous information discovery in the Web of things, so successfully reached the goal by just using the raw data and later on grabbing useful information from that data. Not just grabbing that information but later on also inferring rules/remedies from that data, as we are living in the era of smart systems, and IoT and WoT which are all famous in this domain. For this situation, it converted the system in such a way that it smartly takes raw data from user and as a return, it not only gives information but also infers suggestions from those raw digits.

In this research paper, M3 Ontology is introduced on the Triglyceride control system for the first time based on the M3 ontology framework. Ontologies are becoming essentials for interoperability. The M3 ontology framework has been used in various applications where interoperability is required. We evaluate in this case study triglyceride patient's real-time data from the sensors and work on the challenge of heterogeneity in such a way that the ontology provides a single format for every sensor data. The scope of M3 ontology can cover all fields of life. In the future, we explore more ontologies for different domains of life using M3 Ontology to overcome semantic interoperability.

Future Work Plan: The research on semantic interoperability for different fields of life like energy domain, education and industrial automation shall be carried out. Semantic interoperability has vast advantages in IoT. Advances in industrial automation will be accelerated through semantic interoperability and integrated artificial intelligence. We will develop software and android applications for above mentioned fields.

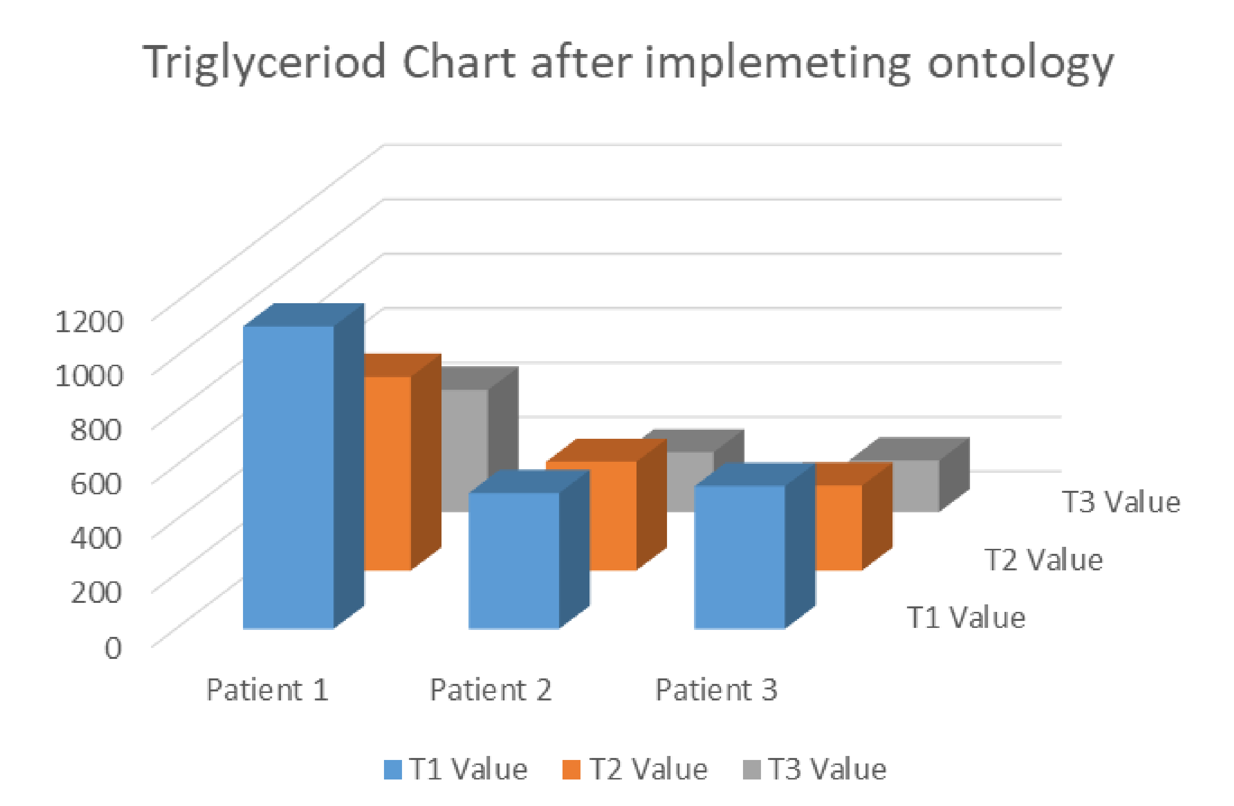

Figure 9: Patients Graph

REFERENCES

Barnaghi, P., Compton, M., Corcho, O., Castro,R., Graybeal, J., Herzog, A., and Page, K. (2011).Semantic sensor network xg final report, w3cincubator group report 28 june 2011.

Barnaghi, P., Wang, W., Henson, C., and Taylor, K. (2012). Semantics for the internet of things: early progress and back to the future. International Journal on Semantic Web and Information Systems (IJSWIS), 8(1), 1–21.

Chindenga, E., Gurajena, C., andThinyane, M.(2016). Towards an adaptive ontology based model for interoperability in internet of things (iot). In IST-Africa Week Conference, 2016. IEEE, 1–8.

Desai, P., Sheth, A., and Anantharam, P. (2015).Semantic gateway as a service architecture for iot interoperability. In Mobile Services (MS), 2015 IEEE International Conference on. IEEE, 313–319.

Tabaa, M., Monteiro, F., Bensag, H., and Dandache, A. (2020). Green Industrial Internet of Things from a smart industry perspectives. Energy Reports, 6, 430-446.

Fotouhi, H., Cˇ ausˇevic´, A., Vahabi, M., and Bj orkman, M. (2016). Interoperability in heterogeneous low-power wireless networks for health monitoring systems. In Communications Workshops (ICC), 2016 IEEE International Conference on. IEEE, 393–398.

Gyrard, A. and Serrano, M. (2016). Connected smart cities: Interoperability with seg 3.0 for the internet of things. In Advanced Information Networking and Applications Workshops

(WAINA), 2016 30th International Conference on. IEEE, 796–802.

Gyrard, A., Datta, S. K., Bonnet, C., andBoudaoud, K. (2015). A semantic engine for internet of things: cloud, mobile devices and gateways. In Innovative Mobile and Internet Services in Ubiquitous Computing (IMIS), 2015 9th International Conference on. IEEE, 336–341.

Gyrard, A., Datta, S. K., Bonnet, C., and Boudaoud, K. (2015, August). Cross-domain Internet of Things application development: M3 framework and evaluation. In 2015 3rd International Conference on Future Internet of Things and Cloud (pp. 9-16). IEEE.

Jayaraman, P. P., Palmer, D., Zaslavsky, A., andGeorgeakopoulos, D. (2015). Do-it-yourself digital agriculture applications with semantically enhanced IOT platform. In Intelligent Sensors, Sensor Networks and Information Processing (ISSNIP), 2015 IEEETenth International Conference on. IEEE, 1–6.

Jayaraman, P. P., Perera, C., Georgakopoulos, D., Dustdar, S., Thakker, D., andRanjan, R. (2017).Analytics-as-a-service in a multi-cloud environment through semantically-enabled hierarchical data processing. Software: Practice and Experience,47(8), 1139–1156.

Jin, W. and Kim, D. H. (2018). Design and implementation of e-health system based on semantic sensor network using ietf yang. Sensors,18(2), 629.

Korkan, E., Kaebisch, S., Kovatsch, M., and Steinhorst, S. (2020). Safe interoperability for web of things devices and systems. In Languages, Design Methods, and Tools for Electronic System Design (pp. 47-69). Springer, Cham

Li, Z., Chu, C.-H., Yao, W., and Behr, R. A. (2010). Ontology-driven event detection and indexing in smart spaces. In Semantic Computing (ICSC), 2010 IEEE Fourth International Conference on. IEEE, 285–292.

Mingozzi, E., Tanganelli, G., Vallati, C., Mart´ınez, B., Mendia, I., and Gonz´alez-Rodr´ıguez, M. (2016).Semantic-based context modeling for qualityof service support in iot platforms. In Worldof Wireless, Mobile and Multimedia Networks (WoWMoM), 2016 IEEE 17th International Symposium on A. IEEE, 1–6.

Pereira, C., Pinto, A., Aguiar, A., Rocha, P., Santiago, F., and Sousa, J. (2016, June). IoT interoperability for actuating applications through standardised M2M communications. In 2016 IEEE 17th International Symposium on A World of Wireless, Mobile and Multimedia Networks (WoWMoM) (pp. 1-6). IEEE.

Parveen, K., Ali, A., and Asadullah, G. (2018). Survey on Operating Systems for the Applications of the Internet of Things. Journal of Information Communication Technologies and Robotic Applications, 9-16

Santos, J., Rodrigues, J. J., Silva, B. M., Casal, J., Saleem, K., and Denisov, V. (2016). An IOT-based mobile gateway for intelligent personal assistants onmobile health environments. Journal of Network and Computer Applications, 71, 194–204.

Shariatzadeh, N., Lundholm, T., Lindberg, L., andSivard, G. (2016). Integration of digital factory with smart factory based on internet of things. ProcediaCIRP, 50, 512–517.

Ning, H. (2018). A survey of data semantization in internet of things. Sensors,18(1), 313. 19. Speiser, S. andHarth, A. (2010). Towards linked data services. In Proceedings of the 2010 International Conference on Posters and Demonstrations Track-Volume 658. CEUR-WS. org, 157–160.

Steinmetz, C., Rettberg, A., Ribeiro, F. G. C., Schroeder, G., Soares, M. S., and Pereira, C. E. (2018). Using ontology and standard middleware for integrating iot based in the industry 4.0.IFAC-PapersOnLine, 51(10), 169–174.

Vermesan, O. and Bacquet, J. (2017). Cognitive Hyperconnected Digital Transformation: Internet of Things Intelligence Evolution. River Publishers.

Yachir, A., Djamaa, B., Mecheti, A., Amirat, Y., and Aissani, M. (2016). A comprehensive semantic model for smart object description and request resolution in the internet of things. Procedia Computer Science, 83, 147–154.

Zhang, N., Chen, H., Chen, X., and Chen, J. (2016). Semantic framework of internet of things for smartcities: case studies. Sensors, 16(9), 1501.