SysIoTML: A Technique for Modeling Applications in the Context of IoT

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Abstract: The Internet of Things (IoT) is a concept that connects smart objects equipped with sensors, networks, and processing technologies that work together to provide an environment in which smart services are brought to users. Systems modeling should be conducted to create IoT Systems and ensure the implementation of a good system. IoT increases the complexity of systems modeling due to novel concepts that need to be addressed. However, there are no established techniques for systems modeling for this specific context. This paper presents the development of a new technique for IoT systems modeling, the SysIoTML, an extension of SysML. Such techniques consider specific aspects of IoT Systems (behavior and interactivity). We proposed the SysIoTML and conducted a concept-proof to analyze the technical feasibility. The developed technique proved useful, and the participants were able to model the proposed problem. The main contribution is to advance IS modeling through a new technique.

1 INTRODUCTION

The Internet of Things is a concept that aims at the digital interconnection of everyday objects to the internet. It is a paradigm that allows composing systems from uniquely addressable objects (things) equipped with the identification, sensation, or actuation of behaviors and processing capacities that can communicate and cooperate to reach a goal (Motta et al., 2018). From primary devices with simple systems solutions to large-scale, high-performance systems that produce and analyze vast amounts of data, IoT will reach all areas of interest (Jacobson et al., 2017), areas that directly involve humans. IoT allows physical objects (sensors, vehicles, buildings, and others) to collect and transmit data, incorporating sensors, software, and other technologies, to connect and exchange data with other devices and systems on the Internet.

Smart devices and services are carried out through the various applications that run in the IoT environment (Miao and Liu, 2016). Various capabilities such as producing/consuming data and online services improve daily life and activities around the world through the context of IoT (Talavera et al., 2017).

IoT scenarios apply to using IoT devices in their daily activities. In addition, IoT applications have some benefits for users to choose the best opportunity in any case, decision-making, management, and monitoring (Ghobaei-Arani et al., 2018).

In recent years, IoT has been widely present everywhere in most aspects of human life, such as cities, homes, universities, industry, organizations, agricultural environments, hospitals, and health centers (Muralidharan et al., 2018). Despite the motivations of the different application domains, they all have a common and shared goal: to provide smart services to increase the quality of human life (Bello and Zeadally, 2019).

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Information Systems, including IoT Systems, benefit from the use of modeling, which helps developers better visualize the system's planning and design, in addition to allowing the development to be more adequate. It should be noted that complex computer systems require a high level of quality, and the search for such systems has motivated the development of modeling methods (Lima et al., 2021).

Literature and industry present modeling languages that aim to create graphical representations of systems, such as UML (Unified Modeling Language) and SysML (Systems Modeling Language). Systems modeling is the process of developing abstract models of a system's components, providing everywhere in most aspects of human life system does (Jacobson et al., 2017). In IoT systems, several additional aspects need to be modeled. These are aspects inherent to this type of system, such as specific behavior and interaction (Motta et al., 2018).

The behavior of an IoT system can help in decision-making and actions because what makes a smart system are the devices used, the decision-making process, and the entire solution architecture (Atabekov et al., 2015). Furthermore, many IoT devices and systems perform functions based on human behavior. Therefore, social relationships (for example, friendship and conflict) of people are very critical, which must be considered in IoT with device-to-device communications (Chen et al., 2018)

Interaction can help to understand the dynamics of a system, its structural organization, and the interaction between objects, especially with the increasing complexity and number of devices. New architectural styles are required to address your needs for scalability, fault isolation, and flexibility (Herrera-Quintero et al., 2018).

This work aims to define a technique for modeling IoT systems, considering the aspects of behavior and interaction. Additionally, we conducted a proof of concept (PoC) with nine participants to verify technique feasibility. The defined technique has four diagrams, extensions of diagrams presented in SysML: Use Case Diagram, Sequence Diagram, Block Definition Diagram, and State Machine Diagram. The results of the study show that the technique is favorable for modeling IoT systems, in addition to being useful and easy to understand, all participants were able to perform the modeling of the experiment, but some difficulties were pointed out in the block definition diagram by some participants.

This paper is organized as follows: Section 2 presents the background; Section 3 presents the technique; Section 4 presents the Proof of concept; and Section 5 presents the conclusion and future work.

2 BACKGROUND

IoT is a recent communication paradigm that envisions a near future, in which objects of everyday life will be equipped with microcontrollers, transceivers for digital communication, and proper protocol stacks. That will make them capable of communicating with each other and with users, becoming an integral part of the Internet (Atzori et al., 2010). The IoT vision can become the foundation to realize a unified urban-scale Information and Communication Technologies (ICT) platform, so unlocking the potential of the vision of concepts such as Smart Cities (Hernández-Muñoz et al., 2011), thus being able to be a concept that enables and provides the main support for Smart Cities. In this section, we present the aspects of IoT modeled in our technique, behavior, interaction, and other concepts related to the research.

2.1 Behavior and Interaction

In (Motta et al., 2018), the IoT Facets are presented, which represent the vision of the different facets that characterize the IoT multidisciplinary. Facets represent different disciplines and knowledge areas involved in IoT. The authors present the challenges involving software engineering and the IoT. An analysis of the IoT definitions identified through a literature review, a report by a state-owned company, and the concerns of professionals were carried out, thus defining the necessary facets for the materialization of IoT. As a result, the problem domain and seven different facets were obtained: connectivity, things, behavior, smartness, data, interactivity, and environment.

Behavior comprises the realization of reactions, so it may be necessary to use software solutions, semantic technologies, data analysis, and other areas to improve the behavior of things. In this sense, all manipulation, analysis, and data processing were encapsulated in this facet, dealing with the implemented behavior and the generated results. The idea of the behavior of the system results from its constituent parts. Behavior is generated by the interaction and collaboration of two or more devices, and the combination of more straightforward behaviors can generate more complex behavior.

Interactivity takes place in the interaction to exchange information between actors and things, and the degree to which this happens. Actors involved with IoT applications are not limited to humans, we also have animal and thing-to-thing interactions.

In the technique presented in this paper, we choose only two of these facets, because modeling the behavior of software can help to a better understanding of the system and the factors that influence their behavior. Interaction modeling can help to understand the dynamics of a system, its structural organization, and the interaction between objects. We believe that, for an initial version of the technique, these two facets are interesting, as they work with the basis of any system, which is how it should behave and interact with the users.

To support the development of applications in the context of IoT, (Motta, 2021) presents an instrument called IoT Roadmap. In IoT Roadmap, evidence is collected for each of the facets, aiming to address some existing challenges of IoT.

In the SysIoTML technique, we used the specific recommendation items for each facet, provided by the IoT Roadmap. These items were used as resources for each facet, and these resources were used to adapt the modeling diagrams. Table 1 presents the characteristics pointed out in the IoT Roadmap for the Behavior Facet, where three properties are defined: IoT object, sensor, and actuator with their respective characteristics. The same table also presents the characteristics pointed out in the IoT Roadmap for the Interactivity Facet.

2.2 UML

The UML is a language for specifying, visualizing, building, and documenting the artifacts involved in software systems, modeling business, and other non-software systems. The UML represents a collection of engineering best practices that have proven effective in modeling large and complex systems (Booch et al., 1999).

A UML profile defines the mechanisms used to adapt the UML metamodel to new platforms or a specific domain. The responsibility of the metamodel is to define a language that will be used to elaborate a model. Thus, the stereotypes of a UML profile will be instantiated from a certain element of the UML metamodel. The UML metamodel is composed of the concepts of classes, attributes, associations, and so on. It is primarily a set of stereotypes, constraints, and sometimes classes and other elements that adapt the UML metamodel to a specific domain or purpose; profiles are external to a model and extend the UML without changing the base metamodel.

2.3 SysML

IoT systems need modeling to be developed with quality. Decision-making must seek an option that presents the best performance, the best evaluation, or the best agreement between the expectations of the decision-maker, considering the relationship between the elements.

In SysML, requirements, and block definition diagrams are often used to describe the hierarchy of a system, such as a tree of parts (e.g. equipment tree). The requirements diagram presents a simple hierarchy of text-based requirements, and the block definition diagram is used to define a system or component at any level of the system hierarchy (OMG, 2019).

SysML is a general-purpose architectural modeling language for Systems Engineering applications. It enables the specification, analysis, design, verification, and validation of a wide range of systems. These systems may include hardware, software, information, processes, personnel, and facilities (OMG, 2019). The Sequence, State Machine, Use-Case, and Package diagrams have not changed from the UML. The block definition, activity, and inner block diagrams have been modified from the UML and the requirements and parametric diagrams are new (OMG, 2019).

3 SysIoTML

In recent years, IoT has been widely used in most aspects of human life everywhere, like homes, cities, farms, hospitals, factories, universities, etc. Therefore, systems aimed at human well-being need to be modeled properly, especially with their behavior and interaction, so that these systems in the development phase are done appropriately, this triggered the need for modeling with a simple notation but complete in the context of IoT.

The IoT Roadmap provides specific recommendation items for each facet. We convert these items into characteristics for the behavior and interactivity facets. Finally, we used these features to adapt existing modeling diagrams that covered IoT aspects.

For adaptation, we used the concept of stereotypes (OMG, 2019). A stereotype is an extensibility mechanism that allows you to adapt or customize models with specific constructs for a particular domain, platform, or development method.

We created a modeling technique for systems in the IoT context, where four diagrams were developed, extensions of the diagrams found in SysML: Use Case Diagram, Sequence Diagram, Block Definition Diagram, and State Machine Diagram.

3.1 Use Case Diagram

The Use Case Diagram presents a simple and easy-to-understand language so that users can have a gen-

Table 1: Behavior and Interactivity Facet Characteristics (Motta, 2021).

Facet	Define	Characteristics
Behavior	IoT Object	The IoT object metadata Identify identification technology Describe the event Describe identification type
Behavior	Sensor	Set sensor related data Describe an abnormal condition Indicate the limit and the desired values Set sensor device Establish rules for the sensor
Behavior	Actuator	Describe manual or automatic mode Locate the action Identity who triggers the action Enter the circumstances to trigger the action - input Establish the consequences of an action - output Identify who acts
Interactivity		Define users, roles, and responsibilities Define data for users and roles Define human-thing or thing-thing interaction Set interaction method (gesture, touch, etc.) Identity interaction IoT object Identify the sequence of interaction and expected result

eral idea of how the system will behave. It identifies the actors (users, other software that interacts with the system, or even some special hardware), who will use the software in some way, as well as the services, that is, the options that the system will make available to the actors, known in this diagram as Use Cases.

In SysIoTML, the actors will be represented through the <<*stereotype*>> Stakeholder, and their relationship with an object will be through a use case, which will communicate with an object through the <<*interaction*>>. The objects will be represented through the <<*stereotype*>> IoT object, with two <<*extend*>>, <<*extend*>> Sensor and the <<*stereotype*>> Actuator. You can have more than one <<*stereotype*>> IoT Object, with more than one <<*stereotype*>> Sensor or <<*stereotype*>> Actuator. Figure 1 shows this diagram.

Some important rules for this diagram: the <<*stereotype*>> Sensor and the <<*stereotype*>> Actuator cannot have use cases directly linked to them. The <<*stereotype*>> Stakeholder and <<*stereotype*>> IoT objects can have use cases directly linked to them.

3.2 Sequence Diagram

The Sequence Diagram is concerned with the temporal order in which messages are exchanged between the objects involved in a given process. A Sequence Diagram usually identifies the generating event of the modeled process, as well as the actor responsible for this event, and determines how the process should unfold and be completed by sending messages, which in general trigger methods between objects.

In SysIoTML, the actors will be represented through the <<*stereotype*>> Stakeholder. Through an initial interaction between the <<*stereotype*>> Stakeholder and the object <<*stereotype*>> object, from there the process, can unfold together with the other three objects: <<*stereotype*>> Sensor, <<*stereotype*>> Controller and <<*stereotype*>> Actuator. Figure 2 presents this diagram.

It is not allowed to create lifelines other than those already established, you can create more than one of those already established.

3.3 Block Definition Diagram

The Block Definition Diagram defines the features of a block and any relationships between blocks, such as associations, generalizations, and dependencies, in terms of characteristics, operations, and relationships. It is used to define the characteristics of each Block in terms of its structural and behavioral characteristics.

In SysIoTML, a block will have three <<*stereotype*>>: <<*stereotype*>> object, <<*stereotype*>> Sensor, and <<*stereotype*>> Actuator, each with predefined values and properties that must be filled in. Figure 3 presents this diagram.

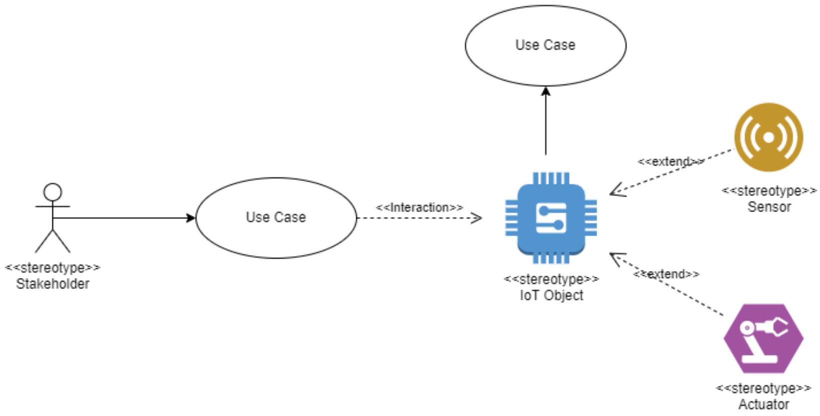

Figure 1: Use Case Diagram.

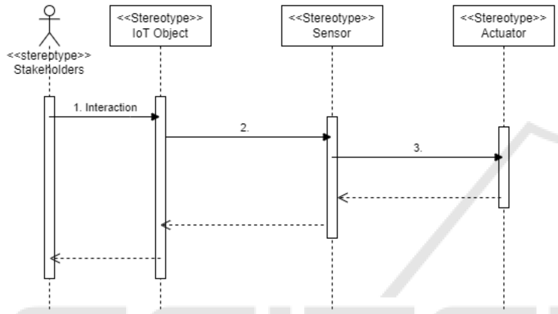

Figure 2: Sequence Diagram.

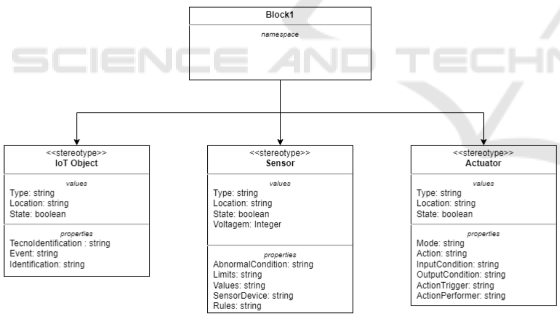

Figure 3: Block Definition Diagram.

3.4 State Machine Diagram

This diagram tries to follow the changes suffered in the states of an instance. It is a type of behavioral diagram that shows transitions between various objects, describing actions, conditions, and consequences. This diagram is interesting for modeling behavior as it can show all possible states of an IoT Object, sensor and actuator.

In SysIoTML, the classes *<<stereotype>>* Sensor and *<<stereotype>>* Actuator will represent changes in states suffered due to an Interaction. The *<<stereotype>>* IoT Objects enables/disables the *<<stereotype>>* Sensor and *<<stereotype>>* Actuator.

4 PROOF OF CONCEPT

The Proof of Concept (PoC) aims to analyze the feasibility of the first version of our technique. To carry out this study, we used an IoT system scenario related to traffic in an urban center.

Traffic signs are the most basic instrument for collecting road traffic data in a city, that is, they allow the management of vehicle and pedestrian traffic flow, as well as the starting point for data acquisition. For example, vehicle and pedestrian count, traffic speed, and congestion. Traffic light control is an important and challenging problem in the real world as traffic signals can provide potential solutions to ensure improved and efficient transport and consumption, energy consumption, environmental protection, increased productivity, and citizen satisfaction (An et al., 2017) (Wei et al., 2019) (Guo et al., 2019).

The work by (Souza et al., 2020) presents the requirements for an experiment with traffic signs, of which we filter seven to be used in our feasibility study, as they are related to the behavior and interaction of the system. The selection of these requirements was validated by a researcher in software engineering. The requirements are:

1. The system must control the traffic pattern of vehicles at the intersection;
2. The system must control the pedestrian traffic pattern at the intersection;
3. The system must store the flow of vehicles on the roads;
4. The system must store the pedestrian flow on the roads;

5. The system must track the traffic pattern related to each road;
6. The system must allow synchronization of traffic signs;
7. The system must allow the detection of the presence of pedestrians

4.1 Conduction

We performed the PoC with nine participants: two have a baccalaureate level and seven have a master level, all of whom have modeling knowledge and some academic or professional knowledge of IoT. The Table 2 presents the profile of the study participants, their academic degree, and their knowledge in modeling and IoT, where, Academic represents only academic knowledge, Academic/project represents academic knowledge and a project, Project/professional represents more than one project or up to six months of professional work and Professional represents more than one year of professional work.

To carry out the study, we used the context of smart traffic signs. Each participant received: (1) a description of the problem to be modeled; (2) guides for using each SysIoTML diagram; and (3) participant characterization and SysIoTML assessment questionnaires. These guides introduce the idea of SysIoTML and explain in detail the use and restrictions of each diagram. Guides are available at: https://drive.google.com/drive/folders/18ypev8Nl7mlNdZ5n5A_ksVLW9c4N1qY1?usp=share_link.

Regarding the technique evaluation questionnaire, participants answered questions about the ease and usefulness of the technique. Additionally, we asked them to evaluate each diagram separately and express opinions about the diagrams. The questionnaire is available at: https://docs.google.com/forms/d/e/1FAIpQLSfsxedBVmCg5hjk5cOdYkX1TKpl8YYPBrThf9nVi74CPkl5rQ/viewform.

4.2 Results and Discussion

Each participant needed about thirty minutes to model each SysIoTML diagram. Regarding the ease of understanding the diagrams, participants indicated positive results. Participant 1 reported that *"The components of the diagrams are easily understood, facilitating their use."*. Additionally, participant three pointed out that *"The diagrams are easy to understand, the guide presents clear and objective information on how it works"*. Similarly, we had positive results for the ease of use of the diagrams, according to participant 1 *"It was possible to use the proposed solution to model the test application"*.

About the models created from the modeling technique, the answers of the participants show that the additional elements are adequate for the modeling of applications in this domain. Participant 2 described that: *"[the technique] allows describing the sensors that make up an IoT scenario and the interaction with them"*. Additionally, participant 8 indicated that *"it was interesting to model using the three domains: Stakeholder, Object, and Sensor, this helped to organize each area and its responsibility"*.

By specifically analyzing each diagram, we can conclude that the diagrams are useful for identifying the elements of smart objects. According to participant 1, *"Extended diagrams are useful. The addition of elements such as smart objects, sensors, and actuators in UML diagrams seems to be interesting and useful"*.

On the other hand, participant 5 pointed out the difficulty in *"understanding how objects/ sensors/ actuators are correlated in a block"* and also stressed the need for *"means of giving clearer internal relationships between actuators/sensors/objects"*. Two participants (5 and 8) suggested that our technique would be better used and easier to "draw" the diagrams if there was some modeling tool with the formats of our pre-built diagrams.

Another point highlighted during the analysis of responses was the applicability of other scenarios of IoT systems. Participant 6 reported that our technique was useful for modeling the proposed scenario, but that it would be interesting to test it in other scenarios, because according to a participant *"I don't know if, in other more complex cases that may have to represent other aspects, there may be some additional need"*.

The researchers involved in defining the technique also analyzed the resulting diagrams for each participant. We identified that the participants were able to model the problem and the requested elements, such as identification sensors. To facilitate the analysis, we made an "oracle", to know what was expected from the resulting diagram.

The "oracle" we did in two steps:

1. In the first, two participants from our group did the experiment with traffic signs separately.
2. In the second, meetings were held with the entire group of researchers to expose the models made and a debate on each point presented.

Our idea was to reach a consensus on what was expected as a result of the modeling done by the participants, in addition to having a way for us to evaluate the resulting diagrams. With the "oracle", we analyzed each diagram. As a result, we found that the modeling carried out came close to what was idealized. However, we also noticed that two participants

Table 2: Characterization of participants.

ID	Academic Degree	Modeling Experience	IoT Knowledge
1	Master's	Academic/project	Academic/project
2	Graduate	Project/professional	Academic/project
3	Graduated	Academic	Academic/project
4	Master	Academic/project	Academic
5	Master's	Professional	Professional
6	Master's	Professional	Academic
7	Master	Academic/project	Project/professional
8	Master's	Professional	Academic
9	Master's	Professional	Academic/project

had difficulties: (1) when creating the Block Definition Diagram, two participants did not provide details of the characteristics. In our guide, we oriented to present/describe the details of each character; (2) Regarding the use case diagram, participant 5 represented a link between the use case and actuator. In SysIoTML such a link is not allowed because the use case interacts only with IoT Object. Figure 4 present the wrong link created by participant 5.

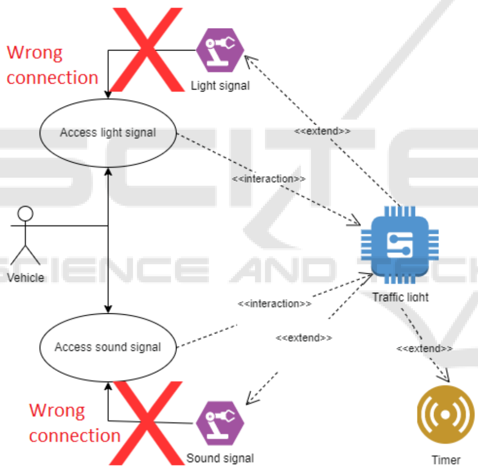

Figure 4: Participant 5 Use case.

After analyzing the resulting diagrams and the participants' responses, we conclude that the technique is appropriate for IoT Systems modeling, but improvements are needed on how to formulate the block definition diagram and rules of the diagram's representations.

5 CONCLUSION AND FUTURE WORK

The IoT is increasingly entering the daily lives of the population through smart devices and systems. Modeling IoT applications is important to ensure the proper development of systems that will operate in the most diverse domains.

In this paper, we present the SysIoTML to model applications in the IoT scenario. The focus of the technique is the behavior and interaction modeling of an IoT system. To evaluate the technique, we conducted a PoC involving smart traffic signs with a group of participants. Each participant modeled the scenario/system separately. With the experiments carried out, we noticed that the technique was useful and was well accepted by the participants.

An evaluative questionnaire about the technique was delivered to each participant. The result of the questionnaire answered by the participants showed that the technique was well accepted by them and was easy to use, despite the indication of some participants for improvements. With the "oracle" we made, we noticed that the diagrams made by the participants came close to what was expected. We also noticed that some participants had difficulties in some points, which were pointed out as improvements in the questionnaire, such as, for example, one of the participants, when assembling the Block Definition Diagram, did not fill in the properties indicated by him with information.

The limitation of our technique is the inclusion only of the IoT Facets of Behavior and Interactivity. This is a limitation because it does not encompass everything an IoT system should have. Another limitation is the use of the technique in only one example. For better validation, the technique must be tested in other contexts.

In future work, first, we have the improvement in the relationship between the object, sensor, and actuator in the block definition diagram since this was a point addressed by some participants. In addition, we need to carry out experiments in other smart scenarios, to better verify the performance of the technique and the development of a tool that helps our technique. And finally, the expansion of the technique to encompass all seven IoT Facets and the Domain Problem, so that the technique encompasses all aspects of IoT.

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