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Socialization of Smart Communicative Objects in Industrial Internet of Things

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Abstract: In the recent past the Internet of Things (IoT) is moving from interactive objects to smart objects. The number of smart devices or sensors built-in becomes larger. The increase in the number of services exchanged between connected objects has led to the creation of a new concept called Social IoT (SIoT), in which heterogeneous or homogeneous objects can interact and request or exchange services, which makes it possible to include social or human actions in the IoT platform. The use of technologies based on the concept of the Internet of Things in applications and industrial sectors has built a new concept of research called the Industrial Internet of Things (IIoT). The integration of the SIoT concept into the Industrial Internet of Things (IIoT) plays an important role in improving system performance in Industry 4.0 and gives rise to the Social Internet of Industrial Things (SIoIT). In this context, we have revealed a new socio-inspired interaction model between industrial communicating objects inspired by sociological approaches that transform objects into socialized industrial communicating objects. These objects form a community, autonomously and dynamically, by exchanging messages to know each other perfectly, and service requests between objects are realized in an adaptive way according to the principles of social interaction governed by socio-inspired strategies and conditions. The model is evaluated using Netlogo multi-agent system simulation environment.

Keywords: Smart object, Internet of Things, Interaction mechanisms, Social Internet of Industrial Things, Social community.

1. INTRODUCTION

The Internet of Things (IoT) is recent and it is growing exponentially. Various real-world objects are connected through the IoT which facilitates machine-to-machine (M2M) communication through the medium of the Internet (Yugha et al., 2020). The importance of IoT that it processes huge amount of data which is detected from various smart devices. The Internet of Things (IoT) combines many diverse technologies and interconnects the various objects of our periphery. In this regard, by using various protocols each object receives its specific address, this object becomes more capable of establishing a relationship with the other objects that surround it (Barbin et al., 2021). In these connections, objects can cooperate to achieve a common goal (Nitti et al., 2012).

The integration of the concepts of human interactions within the IoT gives rise to SIoT (Social Internet of Things). SIoT is an active research axis in which we find social relationships are established between smart objects and their users (Roopa et al. 2020). Social IoT is an emerging IoT paradigm in which smart objects have the power to establish sociable relationships to achieve common or individual interest and perform service exchanges autonomously (Lye et al., 2019). In

addition, SIoT should improve service discovery, information composition and management, and service reliability management (Atzori et al., 2014). To advance and improve the operation of machines in industry, the SIoT concept could be integrated with the Industrial Internet of Things to provide human-to-machine (H2M) communications and machine-to-machine (M2M) interactions. The integration of SIoT in industry is called the Social Internet of Industrial Things (SIoIT) (Roopa et al., 2021).

In this paper, we present sociologically inspired IoT interactions in which, a synthesis of sociological approaches is shown. So, we introduce a new socio-inspired model of the principles of interaction between social industrial objects. The addition of a communicating object to an already stable community is introduced in the following section, presenting the exchange of messages between industrial social objects to determine relations and perform services. The paper ends with a conclusion in which we synthesize our work and identify future work.

2. SOCIAL INTERACTION BETWEEN OBJECTS

Several works in the field of sociology and anthropology have focused on interactions between individuals. The work presented in (Sun et al., 2017), (Wagener, 2012) shows that to

achieve their own interests, people act together to achieve common goals through the principle of cooperation. In (Foa and Foa, 2012), the authors emphasized the principle of authority rank, which translates into the relationship of respect and the principle of sharing in which people share information. In (Tischler, 2010), the principle of competition is well discussed. It is a form of interaction in modern applications not only in the sports field, but in the market, the educational system, and the political system. In the works presented in (Pincus and Ansell, 2013) and (Fischer, 2010) we find that with the principle of resistance, the authors show where one does not make concessions to the other. While with the principle of the market price Fiske also introduce the notion of cost (Mitchell et al., 2012), in which the interactions are organized according to a common scale of values of the elements exchanged.

After an in-depth study of research work in sociology, we have synthesized 6 sociological principles which make it possible to describe most of the relationships and social interactions between individuals. These principles are: Cooperate (Co), Dominate (Do), Compete (Com), Share (Sha), Resist (Re) and Business (Biz). From these interactions, we propose a transposition of these interactions towards communicating industrial objects. We propose a model that consists of six principles of interactions between smart objects as shown in Figure 1.

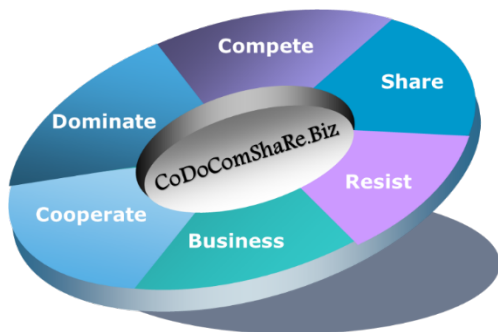


Figure 1. Five principles of interactions

This model is named *codocomshare.biz*, in which all objects can establish relationships and services can be performed to other objects according to one of these six principles.

1.1 Principles of interaction between objects

From these interactions, we propose a transposition of these interactions towards communicating industrial objects.

Cooperate: All industrial communicating objects cooperate, i.e. they share services and perform them for a common purpose. Each communicating object has well-defined missions. To achieve a common goal, the services are performed unconditionally. We have three cooperation strategies:

- Cooperation between communicating objects without conditions.
- Cooperation between communicating objects, in which it is necessary to take into consideration the previous cooperation. In this case, the trust between these communicating objects can be very important factor.

- Cooperation between communicating objects to access a direct or indirect advantage.

Dominate: Industrial communicating objects have a rank of authority. According to the rank of authority, relationships of subordination are imposed and respected in the interactions between communicating objects. For example: the master/slave model can satisfy this type of interaction because it can be seen that only the master can request a service from the slaves who are forced to operate.

Compete: According to the compete principle; there are two ways in which Objects compete to achieve a service. There are two modes for this principle: Several applicants / one executor or One applicant / several executors.

Share: According to the principle of sharing, the sharing of services between all the objects of a community is accepted by all. This exchange can be carried out unconditionally or sometimes with the reciprocity of exchange of services. Sharing strategies are:

- Unconditionally, i.e. fully open.
- Conditioned by the reciprocity of service sharing actions, for example: equivalent to Fiske's Equality Matching.

Resist: Depending on the resistance strategy, a communicating object resists to service execution, it can resist with several strategies:

- Delaying service execution.
- Giving partial information.
- Giving obfuscated information.
- Refusing services totally.

Business: According to the business principle, each service has a predefined cost through a common rating system (bit coin, non-fungible NFT token, etc.), so the notion of monetization of the execution of services between communicating objects is introduced. Through the application of Block Chain smart contracts, monetization of services between objects can be automated and decentralized with security and trust.

3. OPPORTUNISTIC INTERACTIONS BETWEEN INDUSTRIAL OBJECTS

In the interactions between industrial objects, we propose a paradigm shift from deterministic relations to opportunistic relations between more mobile objects. Then each object will be able to have its own interaction strategy n which becomes suitable according to the environment and the strategies of the other intelligent objects that surrounded it.

As shown in Figure 2, the classic M2M interaction is determined with a service request/response.

This type of classic exchange is not suitable, so the emergence of the concept of autonomous smart objects is very important. These objects can simulate human behaviour to interact with each other through interaction principles according to conditions and strategies. This interaction is achieved by applying the SIoT concept, i.e. the service response becomes

smarter. This communication evolves from classic to innovative.

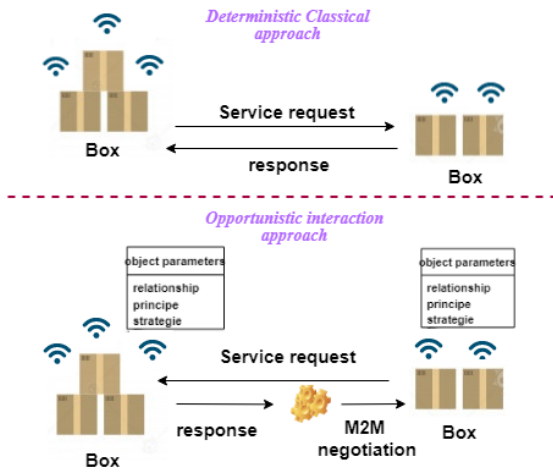


Figure 2. Deterministic / opportunistic industrial object interactions

4. SOCIAL INDUSTRIAL COMMUNICATING OBJECT

The social interaction between Communicating Industrial Sociable objects must have mechanisms, characteristics, attributes, and rules of behaviour to establish social relations and manage social interactions as shown in Figure 3.

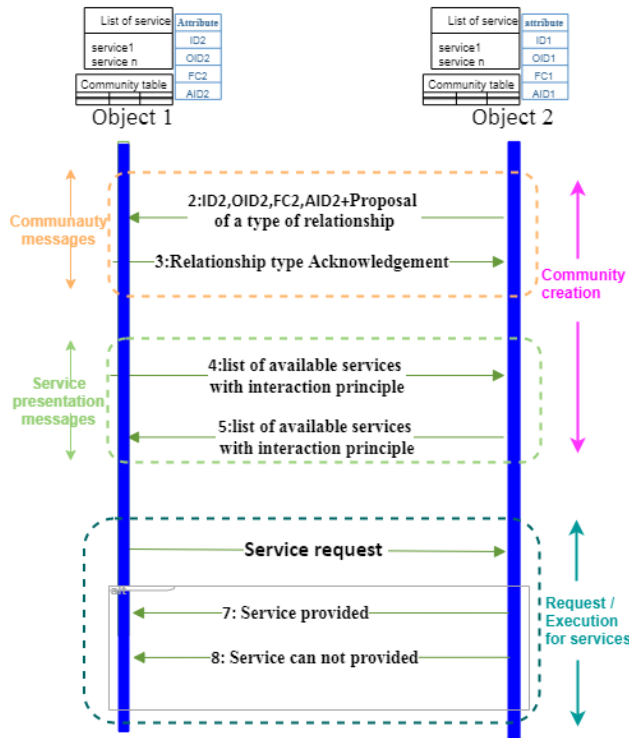


Figure 3. Interaction sequence between communicating objects

To individually differentiate an object from all other objects, an object's attributes determine its own characteristics. Four attributes or identifiers are proposed in (Kilani et al., 2019); Object Identifier (ID), Owner ID (OID), Family Code (FC), Application Identifier (AID). These identifiers define the

social relations between communicating objects. They are used during social interaction with each other.

1.2 Determination of the types of relationships between communicating objects

The approach inspired by human "social relations" and "relational models" shows that the interaction between humans is based on the type of relationship between them. So, for objects to interact effectively with each other, they use human behaviour. In (Atzori et al., 2014) the authors propose five types of relationships: Parental Object Relationship (POR), Co-location Object Relationship (CLOR), Co-work Object Relationships (CWOR), Ownership Object Relationships (OOR) and Social Object Relationships (SOR).

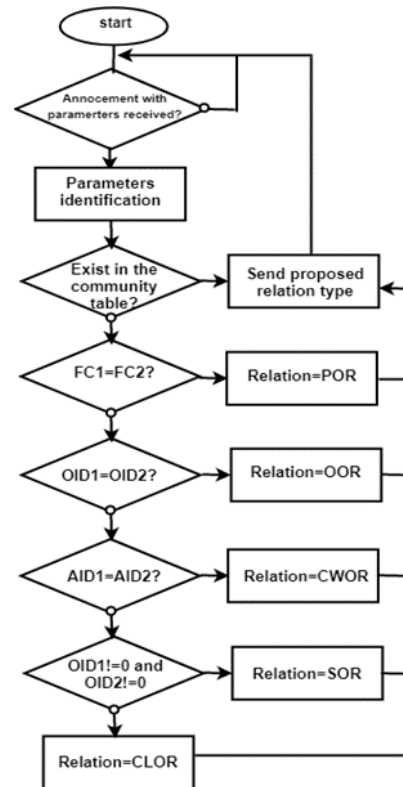


Figure 4. Flowchart of the type of relationship between objects

The POR is established between similar objects belonging to the same production batch as shown in Figure 4. The POR can be used to create robust links in the SIIoT. CLOR is established between objects residing in the same location. The CWOR is established whenever objects periodically collaborate or cooperate to provide a common goal. The OOR is established between heterogeneous or homogeneous objects belonging to the same user. The SOR is established continuously or discretely, as long as the owners are in contact during the lifetime of these objects.

1.3 Community Table :

In our work, an intelligent communicating object keeps a table called community table in which it memorizes the characteristics (ID, AID, OID and FC) and the relations (POR, CWOR, SOR, CLOR, OOR) which are established between socialized industrial objects. Also, a communicating object

can remember objects that it has already seen. Objects are not stable, so the number of objects in a community is variable, resulting in a dynamic community table.

1.4 List of Services:

According to a distributed approach, a communicating object memorizes the list of the services of the other objects, which are in its interpersonal distance. On the other hand, according to the centralized approach, the object does not remember the services of the other objects that it has encountered previously.

1.5 Social community:

By analogy with humans, each object has a list of services that can execute them according to well-defined rules. In the decentralized approach, by the discovery of services of the same community, each object requests and knows the services of all the other communicating objects. The notion of distance is important in communication, so that the contact is effective and comfortable. Each contact is characterized by a distance that must be respected; this distance is called the interpersonal distance. To accommodate this distance, Hall determined the existence of four areas in human's zones as shown in Table I: which are intimate, personal, social, and public zone (Rios-Martinez et al., 2015).

Table 1. Physical distance zones

Distance zones	Mode
Intimate zone	15-40 cm
Personal zone	75 – 125 cm
Social zone	2,10 – 3,60 m
Public zone	7,50 m and beyond

5. CREATION OF COMMUNITIES OF SOCIALIZED INDUSTRIAL COMMUNICATING OBJECTS

When an object is located within the interpersonal distance of another communicating object, therefore, a community will be created or updated. The overlap of interpersonal distances shown in Figure 5 describes two cases: a) the overlap is not sufficient to bring object 1 into the community of object 4; b) the overlap is total so the two objects enter their respective communities.

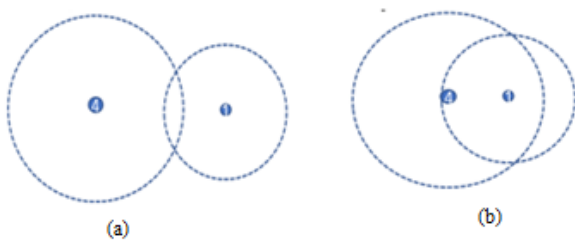


Figure 5. Community made by 2 objects 1 and 4.

In the case where all the objects are located within the interpersonal distance of all the other objects, we can say that these communicating objects belong to the same community as it is presented in figure 6. So, each object has the same community stored in its inner memory.

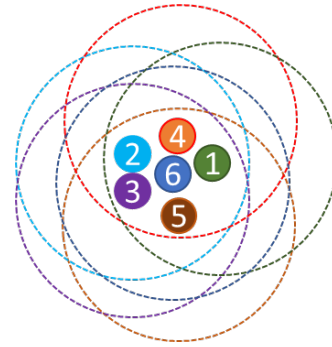


Figure 6. A unique community of Objects.

Each communicating object has its own community table as shown in table II and a specific list of services which are available for all the other objects of its community.

Table II. Individual community for each object

Object	Object's Community
1	2, 3, 4, 5, 6
2	1, 3, 4, 5, 6
3	1, 2, 4, 5, 6
4	1, 2, 3, 5, 6
5	1, 2, 3, 4, 6
6	1, 2, 3, 4, 5

6. NETLOGO SIMULATION

The simulation of our model CoDoComShaRe.Biz was performed by the NetLogo simulator. NetLogo is a programming and simulation language for a multi-agent environment. The exchange of messages under NetLogo is done using a "messaging.nls" extension (Kilani et al., 2022). In this simulator each object has fixed characteristics like the attributes which are: (ID, AID, OID and FC), the community table and the list of services.

After the creation of a unique stable community and following the appearance of a new communicating object. The latter announces his presence by the broadcast of an announcement message. The community's industrial communicating objects respond with a relationship-type proposal message. The new object responds with an acceptance or rejection message for the proposed relationship type. If the relationship is established, each object then sends its service list to this object and the latter responds with its service list.

The announcement and the relationship proposal constitute the community messages. The service list exchange messages form the service presentation messages. Two types of messages are exchanged between industrial communicating objects: community messages and service presentation messages.

As a result of a NetLogo simulation, by adding an object to a unique community of objects, the number of community messages exchanged is represented by figure 7.

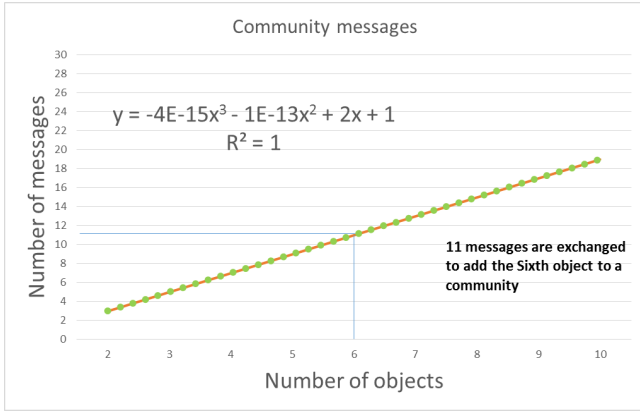


Figure 7. Community messages exchanged by adding a new object

The estimated equation of the curve in Figure 7 is:

$$y = 2x + 1 \quad (1)$$

Equation (1) gives the number of community messages exchanged when a N th new object enters a community already consisting of $(N-1)$ objects. Thus, for an existing community of 5 objects, the integration of a 6th object in this community requires the transmission of 11 community messages.

The estimated equation of the curve in Figure 8 is:

$$y = 2x \quad (2)$$

Equation (2) gives the number of service presentation messages exchanged when a N th new object enters a community already made up of $(N-1)$ objects. Thus, for an existing community of 5 objects, the integration of a 6th object in this community requires the transmission of 10 service presentation messages.

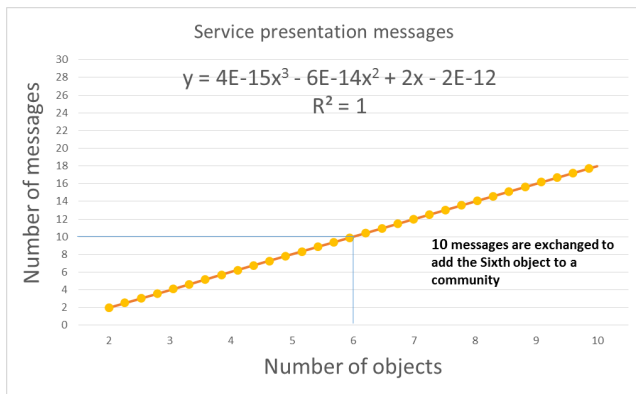


Figure 8. Service messages exchanged by adding a new object

Figure 9 represents the two types of messages, updated community messages and updated service presentation messages according to the number of objects forming a single community.

Thus, the incremental creation of a community of objects generates a number of messages that can be easily calculated by the approximated formula (2) for service presentation messages, and equation (1) for community messages. The total number of messages is fully supportable and manageable by

standard wireless communication technologies used in the IIoT such as ZigBee, Bluetooth, Z-Wave, WiFi.

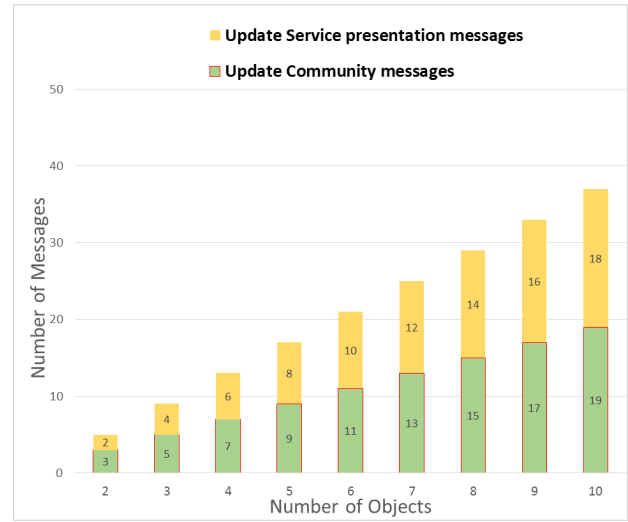


Figure 9. Number of messages between objects by adding a new object in the community

When a community of objects is stable and already exists, there is no new incoming object, then the exchanges are limited only to service requests between objects according to their needs. The message exchange flow is then equivalent to the traffic generated by a classic request/response method, with the addition of the socialized management of interactions between objects.

In the case of the complete creation of a community of N objects "from scratch", the total number of messages generated is given by the following equation:

$$y = \sum_{x=1}^N 4x + 1 \quad (3)$$

The proposed methodology of socialized interaction between communicating objects is totally decentralized because each object implements the same interaction algorithms as described in the previous paragraphs and does not require any centralized management of services or object characteristics.

The method is robust and adaptive because it allows manage communities of objects in an opportunistic way, with a zero-configuration approach. Community interactions are totally spontaneous and deterministic. The complete sharing of the characteristics of industrial communicating objects and their services gives complete visibility for the entire community to each of its members.

6. CONCLUSION

In this work, we have described how industrial communicating objects interact together through a sociological mechanism. This interaction mechanism is based on social behaviour's inspired by sociology research on human interaction. These social behaviours' are introduced in our innovative model called CoDoComShaRe.Biz which is based on six principles of interaction. It makes it possible to manage sociality between objects. The model is dedicated to industrial communicating

objects in the development of Industry 4.0. The interaction of industrial objects is carried out by applying the SIIoT concept, i.e., according to the principles of social interaction (strategies and conditions) the objects accept or refuse the execution of the requested services. The sociability of objects makes it possible to decentralize decisions and to self-regulate conflicts between objects.

The addition of an object to a preset community is done in an autonomous and dynamic way. These industrial objects exchange two types of messages which are the community messages and the service presentation messages that give a complete description for the characteristics and services of all industrial communicating objects. These messages enable adaptive and dynamic sharing of the characteristics and service description of all objects in object communities. Each object in a community dynamically adapts to new incoming objects.

Netlogo simulation proves that our model is efficient and workable by computing all messages exchanged between objects. These messages are used for adding an object to a pre-established community. The simulation results demonstrate that messaging traffic between socialized industrial communicating objects is deterministic and can be estimated a priori by a simple equation. This messaging can be easily implemented by current wireless communication technologies used in industrial applications.

As a perspective of our work, a study of industrial application scenarios of different principles of interaction will be proposed, as well as a practical validation on a real platform of industrial Internet of Things.

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