Information Gathering in Closed-Loop PLM Systems - Social Networks as Models for the Internet of Things?

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Abstract. Different recent approaches from the Product Lifecycle Management (PLM) or Internet-of-Things (IoT) area describe a product-centric view on data and information which are collected by different stakeholders and systems along the lifecycle in order to enhance retrospective analytics, predictive analytics, business decisions, etc. The purpose of this paper is to investigate the basic principles of information sharing, communication and collaboration in traditional human-centric social networks and discuss whether these can be applied to data and information exchange in the PLM/IoT sector. With respect to the methodology applied to this investigation, recent communication mechanisms in social networks as well as in product-centric IoT platforms are systemized and abstracted. Based on the transformation of social network means for IoT, possible improvements of IoT platforms are discussed, resulting in demonstrations of possible PLM usage. In summery, the paper draws implications about the adoption of valuable Social Network means for product-centric usage.

Keywords: Closed-loop PLM, Social Networks, Internet of Things, Data analytics, Social Internet of Things

1 Introduction

The innovation cycles of many products shorten due to different driving forces like customer demand, technical progress, new competitors with substitutive products, etc. Customers are no longer just a passive role in the product development process because they express their product and service experiences and opinions for instance in social networks. Furthermore, products more often contain electronics, so called product embedded information devices, that enable them to be smart and connected in the sense that data, commands and information can be shared and transmitted via internet. The ability of a product to connect to other things, humans or services via internet is reffered to as the Internet of Things (IoT, cp. [1–3]). Obviously, the growing number of data sources with a huge amount of product-centric information clarify that the digital revolution with a growing number of product-integrated information technology (IT) supports product and service innovations. Besides the customer demand for smart and connected products and services, IoT delivers advanced approaches to effectively enable productivity growth and innovation in research and development departments. At this, IoT also encourages that Product Lifecycle Management (PLM) is no longer just a software suite for managing data and processes in the design phase of products but a complete IT-supported concept for managing (perspectively individual) products along the complete lifecycle in all phases. This concept is sometimes referred to as closed-loop PLM [4–6]. Another perspective enhances the physical core product term with a virtual representative that holds product-related data and which is called Digitial Twin or Product Avatar [7, 8]. Accordingly and in summary, enterprises face a growing number of requirements of different stakeholders along the life-cycle to access data of products, which implies the requirement to interact with this new generation of PLM systems.

The magnitude of different data sources and the continously advancing technical progress complicate general standards on common data formats for product-related data, altough attempts exist (e.g. [9]). The purpose of this paper is to investigate whether means of human-centric social networks, namely following entities, subscriptions to topics, (virtual) friendships, hashtags, etc. can be used to overcome the need for precisely defined data exchange formats and interfaces in collecting product-relevant data. At this, this paper should serve as a starting point to compare requirements of different sectors. The basic principles of information sharing, communication and collaboration might be applied to data and information exchange in the PLM/IoT sector meaning that relevant information independent from the source is gathered according to the individual stakeholder requirements and presented to human-beinings. With the so-called Social Internet of Things (SIoT) the paradigm of information distribution via social network models has already been discussed (e.g. [10–12]), however the PLM perspective has not been explicitly considered so far.

The remainder of the paper is organized as follows. In chapter 1 a brief literature review is given to provide background information on recent work about the SIoT and related aspects. With the state of practice also recent IoT platforms available on the market are characterized with respect to obstacles that could occur for future PLM systems. With respect to the methodology applied to this paper, chapter 2 discusses general communication mechanisms in social networks and in IoT platforms and discusses improvements of IoT platforms by means of SIoT. The results are summed up in chapter 3. Finally, chapter 4 draws implications about Social Network means in the PLM software sector and points out possible future research.

1.1 Literature review

IoT is a paradigm which describes that pervasive everyday objects will gain the ability to connect to the internet and to interact and cooperate with each other [3]. Due to the predicted number of devices that will likely connect to IoT – [13] estimates a potential economic impact of \$2.7to \$6.4 trillion per year by 2025 and [14] a total number of 6.4 billion devices in 2016 – the provision of middleware functionality with protocols that support the exploitation of things-related services is the main issue for reliable IoT architectures [15, 16]. Among others, [10–12] therefore the introduction of the concept of social relationships between smart technical objects is referred to as the Social Internet of Things (SIoT).

The main challenges to overcome are:

- An IoT structure which is reliably and scalable in order to ensure network navigability [10, 15, 17]
- Creation and Exploitation of services through (social) service repositories [16]
- Transfer the use of models to study social networks in the IoT domain [10, 15]
- Guarantee a level of trustworthiness like friendships in (human) social networks [10, 15]

The different research works about SIoT address mainly technical issues by adopting means of (human) social networks. [18] proposes to use relationship means (friendships) of typical social networks to share the services of a thing. At this, [19] analyses the social relations between nodes in the internet of things. Further work is done on fundamental IoT architectures based on the model of scalable social networks [10, 15, 17]. At least the combination of traditional human (social) networks with technical IoT networks is investigated by [20–22].

While the general usage of social networks caught the interest of researchers worldwide (cp. e.g. [23–25]), a fundamental consideration about social network means in networks of technical items in the IoT is lacking.

With respect to the PLM software area, concepts for the acquisition of data along the lifecycle are broadly described (cp. e.g. [4, 6]) which could be referred to the topic IoT, anyhow, just few work can be found that addresses the aspect of social networks or SIoT. Considerations about the Product Avatar concept are closest to this idea (e.g. [26]). While the acquisition of product-related information in social networks is state of the art [27], this is not subject of this investigation. On the social-technical collaboration of smart things in the SIoT and the PLM sector, no contributions in the available literature can be found.

1.2 State of practice

Besides considering the available research work on the topic of IoT and in particular SIoT, it is further important to illustrate the state of practice regarding this technologies. IoT is already sucessfully implemented in several industries by the help of IoT platform provider such as ThingWorx [28], Xivley [29] or Oracle [30], to name just a few. Also the leading cloud provider offer IoT solutions such as Microsoft [31], AWS [32] or IBM [33].

Recent IoT system approaches have typically in common, that the “smart” IoT devices are connected via a connectivity layer to a cloud based storage system [1, 34]. The connectivity layer offers standard interfaces such as RESTful WebAPIs, MQTT, OPC-UA, Web sockets, etc. The cloud storage system could be enhanced by further system functionality such as event processing, filtering, device management, predictive analytics, etc. External sources of data could be integrated into most systems and the connectivity layer further provides standard application interfaces for external applications, views, dashboards and similar. The general architecture of IoT systems is provided in the following Fig. 1.

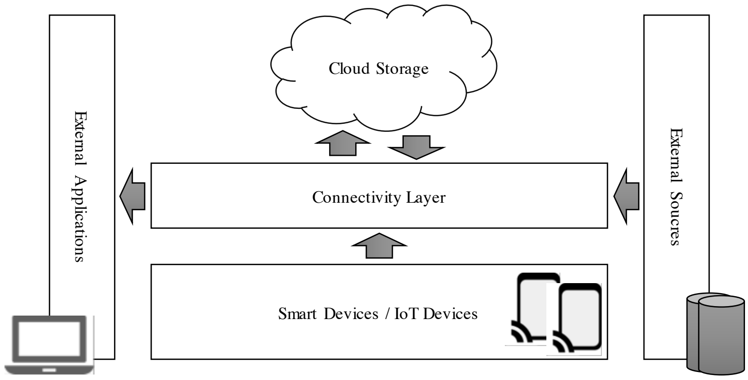

Fig. 1. General architecture of most available IoT systems

A special attention has to be paid to the Message Queuing Telemetry Transport (MQTT) standard, which is on the one hand standardized by ISO [35] and on the other hand already state of practice in several of the mentioned IoT platforms. MQTT offers a publish/subscribe model which is handled by an MQTT broker. That means that sensors (on smart devices) publish their values to a broker instance. Other devices or applications can subscribe to this data channel by addressing the MQTT broker interfaces so that data will be published along the chain to the final device or application [36]. The following Fig. 2 gives a brief overview about the concept.

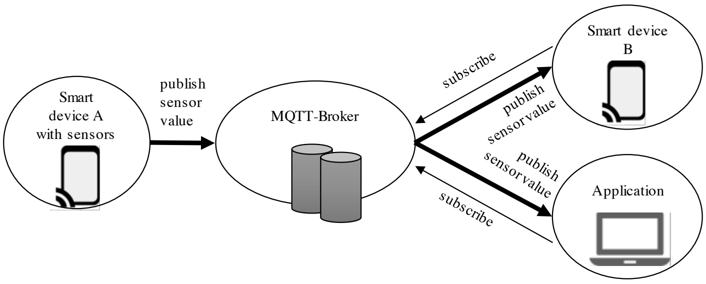

Fig. 2. MQTT publish/subscribe model (according to [36])

2 Method

Based on the argumentation above, the growing number of devices and the intended usage of more and more IoT related information and analysis in human-centric systems like PLM systems lead to the point, that means of (human) social networks could serve as interesting paradigms for communication and collaboration also in SIoT systems. To investigate the suitability of the different means, common known approaches are a) briefly presented, b) discussed in the context of IoT and PLM and c) assessed against the main challenges of broad IoT usage in the following. The main challenges as stated in the previous chapter 1.1 are a) *Trustworthiness* by means of friendship-like structures between smart products, b) *Service discovery* of data and information channels of smart products, and c) *Interoperability* between different platforms.

2.1 Common means for communication and collaboration in social networks

The following common means are taken from typical public and private social network platforms and briefly characterized against the above-mentioned criteria:

Friendships

Persons, organizations and further entities in traditional social networks are able to connect with each other on a platform by expressing so-called "friendships". Friendship implies a relation between the entities, essentially if the friendship has to be confirmed by the invited person. Other functions which are called "following" do not require confirmation. Implicitly friendships form networks of entities that share something together (like interests, same origin, often related to real life).

With respect to IoT, things can be seen entities so that adopting the tool of friendships could also implicitly map networks between devices. The logical relationship between a smart device might contain further smart components as "friends" but also the PLM application or another device. The obvious detriment is that "friendships" have to be classified by means of semantic description (e.g. component, same device, data consuming application, etc.).

Anyhow, the flat hierarchy in the description of networks by the example of friendships addresses explicitly the trustworthiness between smart objects in general as PLM application, for instance, might automatically get access to the components which are connected to them on the second and third level.

Hashtags

Hashtags are tools to describe a continuous text with meta-information. The term derives from the character hash (#) and from the word "to tag" in the sense of assigning a keyword. Hashtags are valuable tools to categorize text messages ad-hoc that means without predefining categories for the messages. At this, it is possible to have flat structures that assign messages to many different hashtags which are also relevant for SIoT. Within messages also the tag "@user" is common to indicate a particular receiver or stakeholder of the message. In consequence, consuming application like the PLM system can follow specific hashtags to get access to different smart objects that post messages under the particular hashtag. A further advantage is that new hashtags that derive from technical progress can easily be added implicitly. However, those categories are not defined in advance contradict to most of today's processes. Hashtags could address the *service discovery* aspect in SIoT.

Interest subscriptions / Groups

In social networks users can express their interest in different topics (like movies, music, etc.), in general by subscribing to a topic (groups) or content provider. Most of these topics are represented by a particular stakeholder which acts as a content provider and accordingly distinguishes the concept from the hashtag concept. Anyhow, the interest subscription implies the agglomeration of entities with the same interest and again forms a layer of network relations. The messaging with interest groups is categorized in advance as it is dedicated to the particular channel. Anyway, using hashtags or sharing messages is not excluded and broadens the reach of the information in the network.

With respect to SIoT, the subscription could serve as a model for sharing the interest of smart objects for instance on same external information sources or services (e.g. a web service with weather data). From this point of view, the ability to subscribe to services addresses the *service discovery* aspect. Anyhow, the concept implies that each single entity has to initiate the subscription, which is comprehensible for human beings but might be challenging to implement it into smart devices. In the broad sense, the concept corresponds to the MQTT standard.

Sharing

In social networks, messages and information by users can be shared which means that an entity is providing the content of the message and the reference to the original author to its own network (friends, groups, etc.). The message has a broader reach and is in general shown on the different user timelines. The basic idea implies that "friends" might be interested essentially in topics and messages of friends which share the same interests.

From today's point of view, it is hardly conceivable that smart objects decide autonomously what might be of interest for other objects. Anyhow, research in the field might show that together with all available meta-information and network structures, this could be possible without predefined rulesets. More comprehensible is the use of this tool in PLM systems, which means that the user as part of the SIoT platform could share data and information as well as essentially already processed information in terms of analytics and forecasts. At this, sharing makes use of *trustworthiness* and could enable *service discovery* and *interoperability* and addresses humans and IoT devices in social-technical networks.

Timeline

The timeline is a functionality often offered to users in social networks as the landing page of the platform. The timeline shows (in chronological sequence) the top messages of entities, friends, interest, groups and similar. At this, the timeline offers the users of social networks, on the one hand, a restricted view on topics with the most likely importance for the consumer. On the other hand, it is the most relevant tool for broadening information in networks.

From the SIoT perspective, the timeline might remain a user interface element but again it could serve as a valuable tool to provide data, information and processed analysis to human actors in the SIoT for instance via PLM systems. At this, it definitely addresses the *service discovery* for humans in the resulting social-technical networks.

Voting (Like, Dislike)
Several social networks offer the possibility to like or dislike a message which accordingly expresses consent with the content or the opposite. The resulting number of likes and dislikes is a measure for importance and reach in social networks.

As a kind of performance indicator, the concept of voting can also be applied to SIoT, as smart objects might vote for services that do analysis or predictions within SIoT. Considering PLM systems with humans involved analysis, predictions, data and information of smart objects that might appear on user timelines can also be voted against importance. At this, voting could contribute to *service discovery* in SIoT.

Instant messaging
Instant messaging (IM) is a tool which is used by users within social networks to send private messages. Although no real technical difference between IM and email can be found, IM is often preferred for short and informal communication. With respect to SIoT, IM equals a direct Device-2-Device communication. From the technical perspective, communication is not challenging but the depending intelligence by context-awareness of devices or even predefined rulesets are research challenges and require at least reliable *service discovery*.

2.2 Platform interoperability between social networks

For the sake of completeness, platform interoperability aspects between social networks will be most likely an obstacle for the penetration of IoT in the market. The problem is foreseeable as today's social networks and state-of-the-art IoT platforms are hardly interoperable. Within this paper, we figured out the following initial approaches of traditional social networks.

Share buttons
Essentially websites and blogs make use of share buttons which offer the users in social networks the possibility to share content (as described before) directly from the particular website in different social networks. Partly it is also possible to "cross share" posts between different network platforms. For IoT and SIoT this aspect might be an example which can be adopted in the sense of sharing or "cross-posting" data channels to other SIoT platforms (even those that are not public but in-house).

Interoperable clients
For social networks clients are available that can sum up information of different networks. Anyhow, this implies individual interfaces to every platform often with the problem that only subsets of the range of functions can be supported. The same challenge is present for IoT and SIoT which should not result in the unilateral connection of one particular PLM system with one IoT platform. Standards for data exchange might temporarily be helpful but will not avoid technical progress leading to the same problem again.

Social media management software
For professionals in social networks (e.g. marketing agencies contracted by enterprises), social media management software exists that is able to serve different social media platforms from one tool. Implications of the interoperable clients apply here alike.

3 Results

From the comparisons of established social network means and challenges of (S)IoT, the following preliminary results include a summarized suitability assessment of social network means for mainly technical aspects of IoT and implications of the results for integration of IoT in PLM systems.

Table 1. Summarized suitability of social networks means

Social network aspect	Direct applicability for IOT	Direct applicability for PLM	addresses SIoT challenge		
			Trust-worthi-ness	Service dis-covery	Inter-oper-ability
Friendships	*yes*	*yes*	*X*		
Hashtags	*yes*	*yes*		*X*	
Interest subscriptions / Groups	*partly*	*yes*		*X*	
Sharing	*partly*	*yes*	*(needed)*	*X*	*X*
Timeline	*no*	*yes*		*X*	
Voting (Like, Dislike)	*partly*	*partly*		*X*	
Instant messaging	*challenging*	*yes*		*(needed)*	
Share buttons	*challenging*	*yes*			*X*
Interoperable clients	*As workaround*	*As workaround*			*X*
Social media management software	*As workaround*	*As workaround*			*X*

4 Discussion and Outlook

The key focus of PLM systems is the human being, in most cases engineers and industrial managers of technical products to be more precise. In addition to the

systematic presentation of implications in Table 1, the investigation indicates, that the consequently resulting social-technical networks have to be considered where PLM software tools are in focus. I.e. users will have to deal with information from many devices in the IoT. At this, established social network functions can be considered and consolidated with the technical implications of managing huge amounts of smart devices, as a dynamic selection of relevant data and information is promised.
Based on the first investigation in this paper, the authors will spend further effort in demonstrating the complete chain of integrating IoT data into PLM systems by means of social network functions enhancing the product avatar concept.

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