Towards Open Innovation in Embedded Systems

Completed Research Paper

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ABSTRACT

By opening up a technology, firms can incorporate external actors to improve their products or to develop new applications on top of it. This phenomenon is discussed in the literature as open innovation (Chesbrough, 2003). An embedded system is an example of a modular and traditionally closed technology where parts of the system can be opened in order to stimulate innovation. In this paper, we want to explore how firms can pursue the opening of their embedded systems and their organization in order to unleash the potential of open innovation. By conducting twelve explorative interviews with experts in the field of embedded systems, we discovered three different forms of embedded systems openness and explored technical, internal and external organizational challenges associated with these three forms of openness.

Keywords

Embedded Systems, Open Innovation, Open Technologies

INTRODUCTION

Embedded systems (ES), in contrast to general-purpose computer systems like personal computers, are applied computer systems designated towards a particular function (Noergaard, 2005). ES can be found in a wide range of devices ranging from automotive electronics, aircraft electronics, trains, telecommunication, medical systems, military applications, consumer electronics, fabrication equipment, to smart buildings (Marwedel, 2010). Due to increasing hardware capabilities, additional functions can be implemented in ES, offering potential for new applications. From the perspective of ES producers, this offers a chance to enhance their systems with innovative applications. This can for instance be seen in the increasing capabilities of today's smart phones, where the so-called "apps" are a major success factor. The extent of innovative new functionalities largely depends on external actors contributing complementary applications to the existing platform. To enable external actors to participate in the development of an ES, firms both have to open their organizational system as well as their technical systems. In this paper, we argue, that a parallel opening of the technologies themselves increases the potential for innovation to a much higher extent.

We explore potential approaches for the opening of ES and the challenges associated with it. In the context of this paper, opening of ES refers to the possibility for external actors to enhance an ES without necessarily having to cooperate with the producer. Our research question is how firms can open their embedded systems and their organization in order to enable open innovation. We refer to ES firms as firms offering which incorporate ES in their products and not just specific components of an ES.

OPENNESS OF EMBEDDED SYSTEMS

Based on the research question, two different but interrelated facets of openness are considered: (1) the opening of ES which constitutes a technical perspective and (2) the organizational opening of ES firms to enable open innovation. In order to enable external actors to change an ES, thus enabling open innovation, firms need to technically open their ES to a certain degree.

In the context of technologies, openness refers to the "easing of restrictions on the use, development and commercialization of a technology" (Boudreau, 2010). This definition presupposes a certain degree of technical opening, but emphasizes organizational and business model aspects as well, as it addresses what external actors are allowed to do with a technology. Therefore, the notion of opening a technology is considered in a broader context also including organizational procedures and structures such as legal arrangements.

A similar definition of openness can be found for technical platforms. A platform can be conceptualized as a "technical architecture that allows compatible complements to use it" (Gawer, 2009). Openness of platforms refers to the degree to which there are no restrictions for developers or end-users on participation, development and use (Eisenmann, Parker, & Van Alstyne, 2008). An ES which is opened basically shares the characteristics of platforms, because similar to platforms it constitutes a technical architecture which allows the development of additional compatible elements. Although ES are usually designated towards a specific application (Marwedel, 2010), by opening them for complementary development, they are moving more towards the direction of platforms. Openness itself can be seen more differentiated than just being a dichotomy of open and closed. It is possible to open only parts of a system and keep other parts closed (Balka, Raasch, & Herstatt, 2010). According to former research, many technology systems are neither totally open or closed, but rather partially open (West, 2003). Thereby, partial openness refers to a certain degree of modularity, where openness in operationalized in particular modules. Modularity refers to a continuum describing the possible separation and recombination of the components of a system (Schilling, 2000). In the next two sections, the technical and organizational opening for open ES will be explored.

Technical opening of ES

In contrast to other technical systems, opening of ES needs to account for a rigid technical characteristics challenging ES openness. ES consist of hardware (HW) and software (SW) parts (Marwedel, 2010). Openness principles in the context of tangible products like HW have been called open design (Raasch & Herstatt, 2011). Regarding SW openness, an open architecture allows the use of third party components in order to create a software system (Alspaugh, Asuncion, & Scacchi, 2009). Although ES consist of HW and SW parts, we refer to technical openness in terms of software as the focus of this paper is on enabling the development of additional software applications for existing ES platforms.

Characteristics like real-time or dependability characteristics are not allowed to be violated, as they ensure the proper functioning of the ES. Often, ES operate in safety-critical environments with severe consequences in case of failure, either threatening material damage or human safety (Colnaric, Verber, & Halang, 2007). The requirements posed on ES are dependability requirements (which entails reliability, maintainability, availability, safety and security), real-time requirements and efficiency requirements (Marwedel, 2010; Noergaard, 2005).

Organizational opening for ES

Regarding organizational opening literature on open innovation (OI) provides some insights. In terms of OI, organizing for openness still represents a challenge to which the literature did not provide a comprehensive model so far (Giannopoulou, Yström, & Ollila, 2011). One aspect which is challenging for firms implementing OI is the required organizational structure, as firms are often not attuned to collaboration with a wide variety of actors (Elmquist, Fredberg, & Ollila, 2009). Firms also need to have the absorptive capacity to incorporate external innovations and being able to overcome internal resistance like the "not invented here" syndrome (Laursen & Salter, 2006; West & Gallagher, 2006). Adopting an open strategy requires the establishment of corresponding organizational structures and processes (Giannopoulou et al., 2011). According to Baldwin (2012), the management of distributed innovation in ecosystems, based on an underlying technical system, constitutes a key challenge towards organizational design. In particular, an understanding of the technical characteristics of the system is required in order to inform organization design (Baldwin, 2012).

RESEARCH DESIGN

Although there are a variety of factors, both technical and organizational, which are described in the literature, the concept of ES openness still remains unexplored. To our best knowledge, there is no comprehensive overview of technical and organizational factors influencing potential openness of ES. Thus, we want to explore how firms can pursue the opening of their embedded systems and their organization in order to enable open innovation.

Data Collection

In order to address the research question, a qualitative research approach based on explorative expert interviews has been chosen. In total, 12 interviews with representatives from different firms focusing on the development of ES have been conducted using a semi-structured interview guideline. The interviews took place between June and September 2012. The experts were selected based on their expertise in the field of ES both from a technical as well as a business perspective. Ten of the experts work for international companies, one participant works for a national company based in Germany and one expert holds a position as a full-time researcher in the field of ES. Table 1 provides an overview about the organizations' focus and the position of the participants. The length of the interviews was between 45 and 110 minutes. Subsequently, the recorded interviews were transcribed verbatim. The interviews were started with a general question about current trends and challenges in the field of ES. To prepare a common ground, the first part of the interviews referred to the concept of ES openness. The interviewees were asked about approaches to ES openness and about different degrees of ES openness. In the second part, technical aspects relating to ES openness were explored. In the third part, the organizational aspects relating to ES were discussed.

Role of interviewee	**Focus of the organization**
Manager, business development	Product engineering in healthcare / telecommunication
Project Manager, SW development	Electrical Engineering / Automotive
BU manager	Consulting in Software & Product Engineering
Department manager	ES producer in the automotive industry
CEO	Software development in the fields of automotive and medical engineering
Senior software engineer	ES software development
CTO	Consulting in Software & Product Engineering
CEO	GUI development for embedded devices
Researcher	Computer Science Chair at University, Embedded Systems
Consultant, R&D	Electrical engineering for Industrial Machines
Senior Consultant	ES software development
CEO	Consulting for smart products

Table 1 Background of the interview partners

Analysis

All interview transcripts were analyzed in-depth by two independent researchers during September until November 2012. Data coding and qualitative content analysis was supported by the qualitative research software MAXQDA based on content analysis procedures to code data (Mayring, 2002). Coding was done by two independent parties and then compared by following an analyst triangulation process (Yin, 2008). If data collected from the various sources were inconsistent or contradictory, we went back to the interviewee to clarify issues and compared the findings with existing literature. The content analysis was driven by our research question. In literature, openness has been considered in the context of platforms, mainly considering business model aspects. Here, openness in the context of ES was analyzed considering technical and organizational factors influencing ES openness. For data analysis, we relied on the summarizing content analysis according to Mayring (2002). For the summarizing content analysis, three steps were conducted. First of all, the coded text sections were paraphrased in order to allow generalization in the second step. Thirdly, the reduction was conducted by following the selection, bundling, construction and integration of the paraphrases. The categories were developed by relying on the inductive category development process.

RESULTS

Forms of Embedded Systems Openness

As it has already been mentioned in the theoretical part, the notion of ES openness which incorporates both a technical as well as an organizational perspective has not been elaborated in the literature. Therefore, one goal of this study was to find an integrated perspective on ES openness considering both technical as well as organizational factors.

The interview partners described three different forms of openness in the context of ES, which can be distinguished to the degree to which external actors are involved. The first form, which does not necessarily enable externals to participate, circulated around the implementation of common technical standards and the use of publicly available software. This could for example be the use of embedded linux or Android on the operating systems layer, but also the use of open libraries or open standards. The motivation for this form of openness is not necessarily to involve externals, but there are other motivations as well. According to one interview partner: *"First of all, a proprietary ES has been built and then it has been realized, that something new is required and that there are already a lot of open approaches existing and it would not be profitable to build up these resources internally."* This approach towards openness is primarily motivated by reducing costs and compensating missing internal resources. As this approach can be implemented without the need to involve external participants, it can be conceptualized as internal openness.

In contrast to internal openness, the other approaches towards openness are motivated by involving externals and therefore can be clustered as external openness. Based on the data, there are two forms of external openness. There is the more traditional approach of involving externals on the basis of a contract relationship: *"They would make an NDA and then some opening can occur. This is not that unusual."* This form of openness is not particularly new and already widely practiced, however, by implementing internal openness beforehand, the cooperation with external partners would be facilitated. To protect IP, this form of openness is often accompanied by contractual agreements like NDAs. As it is practiced with partners known to the firm, it can be conceptualized as network openness.

The second form of external openness is market openness. Market openness, in contrast to network openness, does not restrict potential external contributors to the ES, but external actors can themselves extend the ES without necessarily consulting the ES producer. Both forms of external openness, network and market openness, require defined external interfaces of the ES in order to change the system or build new applications on top of it, as one of the experts stated: *"By using defined interfaces, I do not see a problem for additional applications, as long as the interfaces are secure. However, I see a problem if it is possible to implement every kind of source code"*.

Another result of the interviews was that internal openness can be seen as a major facilitator for the two forms of external openness. However, internal openness does not necessarily lead to external openness, but can also be pursued by itself, as one interview partner stated: *"At the moment, we have a closed system based on an open platform, but we do not open it at the moment. When we open it, then we do it by involving the particular customer"*

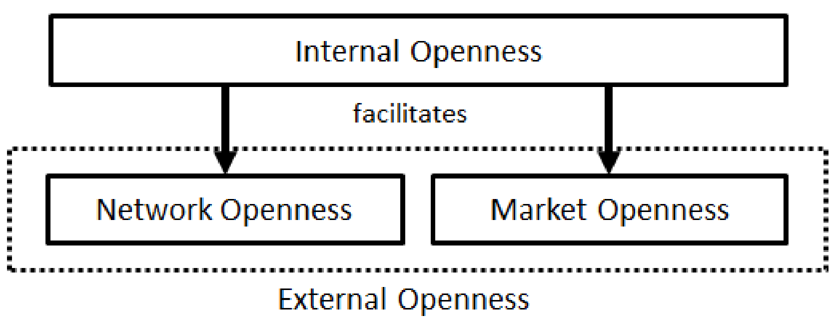

Figure 1 Forms of ES Openness

The three forms of ES openness are depicted in Figure 1. These forms of openness have a similar focus as technological or platform openness. They also refer to the possibilities for external actors to participate in the development and commercialization of ES.

Technical factors influencing ES openness

From a technical point of view, the two most important influencing factors towards openness are safety and security. One expert stated: *"A common barrier is that ES are steering technical processes characterized by safety requirements. To balance between safety and openness is often difficult"*. To balance these different requirements, a common suggestion was to divide the system into a critical and a non-critical part where only the non-critical part should be subject to openness. As one interviewee put it: *"The current trend is that the different [safety-/security-critical and non-safety/security-critical] functionalities have to be put together. And when you want to do that, you have to ensure strict isolation"*. Real-time constraints are another technical characteristic of ES which need to be insured. When opening ES to externals, the ES producer needs to ensure, that new applications made by third parties do not compromise these constraints.

One goal of internal openness, relying on open software platforms and standards is also of particular importance to external openness strategies. These two foundations have been explicitly named by a couple of interview partners, for instance: *"In my opinion, standards are the key to success. And the opening of an existing ES solution does only work, when there is some kind of open operating system on the ES"*. The establishment of standards is also crucial to external openness as it attracts external actors: *"When a standard or an open interface has reached a critical mass, some kind of community emerges or a pool of experts from which a firm can benefit"*. Therefore the crucial role of standards for the development of complementary applications as emphasized e.g. by West (2003), Galvin (2008) or Grøtnes (2009) has been confirmed in the context of ES. In particular, ES producers need to provide standardized interfaces to facilitate the development of new applications from external actors. Another requirement is a flexible architecture which is able to cope with a wide range of requirements. This can be addressed by implementing internal openness, as open platforms often provide more flexibility.

For many ES firms, ES openness is dependent on the availability of cheap, yet capable hardware resources: *"For ES, every cent is important…every reduction of costs leads to more potential for openness"*. For external openness, to incorporate external actors, documentation and in some cases also tool support is required to facilitate the development of new applications.

Based on these results it can be seen that the technical factors can be categorized into technical constraints and technical requirements of openness. Technical constraints determine the potential degree of openness, whereas technical requirements for openness provide guidelines to realize ES openness. Some of the aspects like standardization have already been explored in older literature, e.g. by Rashid et al. (1989), however, the goal here is to collect all relevant aspects in the context of ES openness. The results of this section have been depicted in Table 2 with the numbers showing how many interview partners mentioned the particular aspect. From a technical point of view, both forms of external openness, network and market openness face the same constraints. However, when pursuing market openness, there is a higher risk of violating these constraints.

	Technical constraints	**Technical requirements**
Internal openness	*No constraints found*	technical architecture (3); standardization (11); HW resources (4)
External openness	safety and security (10); RT-Constraints (5);	technical architecture (3); standardization (11); HW resources (4); connectivity (2); documentation and tool support (5); isolation (3)

Table 2 The influence of technical factors on ES openness

Organizational factors influencing ES openness

One result of the data analysis was that the organizational factors influencing ES openness can be subdivided into internal and external organizational factors. Internal organizational factors refer to internal capabilities the organization needs to implement for openness. External organizational do not concern the internal organizational structure itself, but result from external requirements.

Internal organizational factors influencing ES openness

Internal Openness with its focus on open platforms requires corresponding internal know-how, as one interviewee put it: "*with innovative applications in this sector, the complexity also rises, leading to more required know-how"*. As proprietary ES are more dedicated to designated functions, introducing open platforms would provide more flexibility. One interviewee stated: "*the employees and managers need to be able to deal with this kind of flexibility…and this flexibility also requires a broad body of knowledge*". To increase flexibility and handle uncertainty, internal openness requires a stronger focus on communication and cooperation between the employees and less hierarchical relationships. One factor which has to be taken into account regarding the implementation of more organizational flexibility is internal resistance. However, internal resistance constitutes a barrier to openness *"Especially the not-invented-here syndrome is one of the greatest barriers for people who have developed an ES in the last 15-20 years"*.

Due to the increased uncertainty and new ideas flowing in when involving externals, external openness requires a higher level of organizational flexibility. As one interview partner said: *"The potential, of course is that new ideas flow in. But at the* *same time, this is related with possible drawbacks: that you need innovative processes to handle the inflow of new ideas internally".* Therefore, ES firms need to be able to assimilate external knowledge and ideas. These capabilities of firms are especially addressed by literature on absorptive capacity, e.g. Cohen & Levinthal (1990). The field of absorptive capacity has been widely researched from different theoretical perspectives and has been informed by a great variety of empirical evidence (Volberda, Foss, & Lyles, 2010). The role of absorptive capacity in the context of open innovation has e.g. been explored by Newey (2010). Furthermore, the cooperation with unknown external actors requires that these actors get support from the ES firms when developing new applications.

Another factor driving internal openness and network openness is to reduce costs. By reusing existing open software components, the complexity may rise, however, it is less costly than developing components such as an operating system or special libraries. Furthermore, when entering new markets, the risk of losing money is lower when involving external partners. One interviewee stated: *"When you want to enter in a new business sector where you do not have much experience, where the risk is too high, you would search for a partner to whom you would open your system."* However, in the case of network and market openness, the additional support requirements also lead to increasing costs.
Table 3 shows the internal organizational factors firms need to take care of regarding the different forms of ES openness. The second column shows the internal organizational factors relevant to a specific form of openness, whereas the third column shows the factors the three forms of openness have in common.

<table>
<tr><th></th><th colspan="2">Internal organizational factors</th></tr>
<tr><td>Internal openness</td><td>possibility to reduce costs (5)</td><td rowspan="3">Factors in common:
increase organizational flexibility (3); reduce internal resistance (4); required know-how (2)</td></tr>
<tr><td>Network openness</td><td>additional support requirements (3); possibility to reduce costs (5)</td></tr>
<tr><td>Market openness</td><td>additional support requirements (3); ability to assimilate external knowledge and ideas (2); communication among technical staff and management (3)</td></tr>
</table>

Table 3 The influence of internal organizational factors on ES openness

External organizational factors influencing ES openness

In the case of network and market openness, additional challenges arise due to legal requirements. Of particular importance are liability aspects. For some products, especially safety-critical products, ES firms need to certificate their systems whenever changes occur. One expert stated: *"There are a lot of certificated devices which are not allowed to be customized as they would lose their certification."* On the one hand, this increases safety when opening an ES. On the other hand, certification requirements often lead to additional overheads in terms of time and cost. Regarding market openness, the protection of IP is of particular importance. In contrast to network openness, where firms can protect their intellectual properties for instance by NDAs, such mechanisms are harder to enforce. Another important factor is user acceptance. With additional applications for an ES, the end users must be able to cope with the increasing product complexity. For instance, when considering application areas like smart home, the users might be overburdened by new functions. Another aspect is the field of data privacy.
For the success of market openness, the ability to control an ecosystem is a critical factor. This has been expressed by one of the experts: *"What you can see here, what Apple has demonstrated that the firm being in the center of an ecosystem earns most of the money.*" For ES firms, according to this expert, one of the reasons why ES refrain from establishing an ecosystem is "*to realize where the ecosystem is located*".

Summarizing, it can be said, that the experts have put particular emphasis on the legal aspects (IP protection and liability) when opening an ES to external participation. One interview partner stated: "*Regarding organizational factors…IP protection and liability are definitely the most important ones*". The handling of these factors can decide between success and failure of ES openness: *"First of all, when a system gets opened, there is the risk, that certain safety aspects are not fulfilled anymore and I am responsible for the liability…and the other risk is, that I loose intellectual property when I open my system* *too much"*. IP protection has been confirmed by most interview partners to be one of the most important factors ES firms need to consider when opening ES. To ensure IP protection, *"only the parts of a system will be opened which enable a broader utilization of these systems…for this reason, I would claim that the trend is towards closed systems with open interfaces"*. This seems to confirm the notion of IP modularity in the platforms literature, that ES firms implement modularity in their products by considering the criticality of their IP. In table 3, the results concerning the external organizational factors have been summarized.

	External organizational factors
Internal openness	*(no external organizational factors according to the data)*
Network openness	certification requirements (6); liability (6)
Market openness	certification requirements (6); liability (6); IP protection (7); data privacy (2); user acceptance (1); control of the ecosystem (2); product life span (2)

Table 4 The influence of external organizational factors on ES openness

CONCLUSION

The aim of the paper was to explore how ES firms can pursue the opening of their embedded systems and their organization in order to enable open innovation. Resulting from the expert interviews, it has been shown that ES firms have to master technical, internal and external organizational challenges when opening their systems. Regarding ES openness, a conceptualization has been provided, which categorizes different types of openness, namely internal, network and market openness. Furthermore, internal openness greatly facilitates network and market openness. When pursuing internal openness, the primary objective is not to enable open innovation, but other motivations like saving costs or introducing a stable technical architecture are the main reasons. To implement internal openness, firms would need to move towards open platforms and standardization. In addition, organizational challenges like internal resistance have to be overcome. When pursuing external openness, technical characteristics like safety and security are especially significant due to the threat of violation by external applications. Therefore, from a technical point of view, openness is largely determined by the degree to which the isolation of safety- and security-critical parts can be ensured. In addition to the technical factors, ES openness is also strongly influenced by external organizational factors, mainly legal issues like IP protection and liability aspects.

This paper has several limitations. Due to the broad application areas of embedded systems with a broad set of different requirements and in regard to our limited data base, the results of the interview study can only be generalized to a limited degree. Therefore, further research would be needed to provide a deeper insight into different fields of embedded systems. This paper can be seen as a first step towards researching the notion of openness in the field of ES. The different facets of openness could also be investigated more thoroughly, especially concerning the lessening of restrictions on use, development and commercialization of ES. Furthermore, the results do not yet consider openness on a modular level. As it has been seen, partial openness can be achieved by opening particular modules. Especially the influence of critical factors like IP protection or liability on potential openness would be of interest. Besides legal aspects, further research on the cost aspects of ES openness would also be required. From a technical point of view, another research question would be to explore the influence of openness on the architecture of ES. This paper shows relevant factors regarding ES openness, but the degree to which these factors are crucial for the decision towards openness and how they influence firms' decisions in pursuing ES openness still needs to be further explored. Opening ES also challenges existing business models. In particular, by opening ES, firms have to shift their focus on managing the ecosystem of firms emerging by opening their systems.

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