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On the Activeness of Physical Internet Containers

Yves Sallez, Benoit Montreuil and Eric Ballot

Abstract The aim of the innovative Physical Internet (PI) concept is to reverse the unsustainability situation existing in current logistic systems. In the PI approach, the goods are encapsulated in modularly dimensioned, reusable or recyclable and smart containers, called PI-containers. This paper focuses on the design of such containers and more particularly on their associated activeness. This capability allows the PI-container to have an active role for its mission and in the PI management and operation. After a presentation of the physical and informational requirements associated to PI-containers, the notion of activeness is detailed and the main research issues are presented.

Keywords Physical internet, Smart container, Activeness, Intelligent product

1 Introduction

According to [1, 2] the current logistic systems are known to be unsustainable economically, socially and environmentally. To concurrently reverse this situation on the three points of view, the authors introduce the innovative Physical Internet

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(PI) concept. This interconnected logistics system is based on a metaphor of the Digital Internet. By analogy with data packets, the goods are encapsulated in modularly dimensioned, reusable and smart containers, called PI-containers. The ubiquitous usage of PI-containers is to make it possible for any Logistics Service Provider to handle and store any company's products because it will not be handling and storing products per se. In that context, the design of efficient and adequate PI-containers is a main issue. Both physical and informational aspects must be considered in this design. Indeed a PI-container must not be considered as only a "standardized" container with a cargo. As outlined in [2], PI is to exploit as best as possible the capabilities of smart PI-containers connected to the Internet of Things, and of their embedded smart objects, for improving the performance perceived by the clients and the overall performance of logistics systems and of the Physical Internet. Through the increasing of its communicational and decisional capabilities, the PI-container can play an "active" role by itself in the PI management. This paper introduces the notion of PI-container activeness and highlights the main research issues in this field.

Nowadays logistics deals only with passive (bar coded or passive RFID) objects. This situation limits the available information both in frequency and accuracy. For instance, in many supply chains the actual lead-time at the pallet or card box levels is not known. Usually, retailers do not even know the exact shipping location of inbound goods (often different from the manufacturing place). Despite the anticipated benefits, the cost of reading the high flow of data required to reach accurate and real-time information is still too high for widespread adoption.

The reliance on active objects is a way to overcome this problem by autonomous communication not only to gather information but also to enable decision-making processes that will open new savings opportunities such as real-time routing to the market and accurate withdrawal.

The paper is organized as follows. The physical and informational requirements for the design of PI-containers are introduced in Sect. 2. Section 3 describes the notion of activeness, in general and in the context of PI-containers, and then introduces different classes of activeness. Section 4 proposes different research issues in the field of PI-container activeness. Finally conclusive remarks are offered in the last section.

2 Requirements for the Design of PI-Containers

The fundamental PI concept relies on the use of standardized containers that are the fundamental unit loads. Physical goods are not directly manipulated by the PI but are encapsulated in standardized containers. These containers are moved, handled and stored in the PI network. The physical and informational requirements are respectively presented in the two following sections.

2.1 Physical Requirements

As exposed in [1, 2], the key functional specifications of PI-containers are:

- Coming in various modular sizes, from the cargo container sizes down to tiny sizes;
- Easy to handle, store, transport, seal, clench, interlock, load, unload, construct, dismantle, panel, compose and decompose;
- Made of environment friendly materials, with minimal off-service footprint;
- Minimizing packaging materials requirements through the enabling of fixture-based protection and stabilization of their embedded products;
- Coming in various usage-adapted structural grades;
- Having conditioning capabilities (e.g. temperature) as necessary;
- Sealable for security purposes.

As introduced in [3], three PI-containers categories can be distinguished: transport, handling and packaging containers. The relationships between the different categories of PI-containers and the physical goods they are to encapsulate are summarized in Fig. 1.

- The **transport containers**, or T-containers, are the large entities transported by the different types of vehicles (trucks, trains, ships...) on the PI networks. They are designed to be easily carried, to endure harsh external conditions and to be stackable as usual maritime shipping containers. They can contain physical

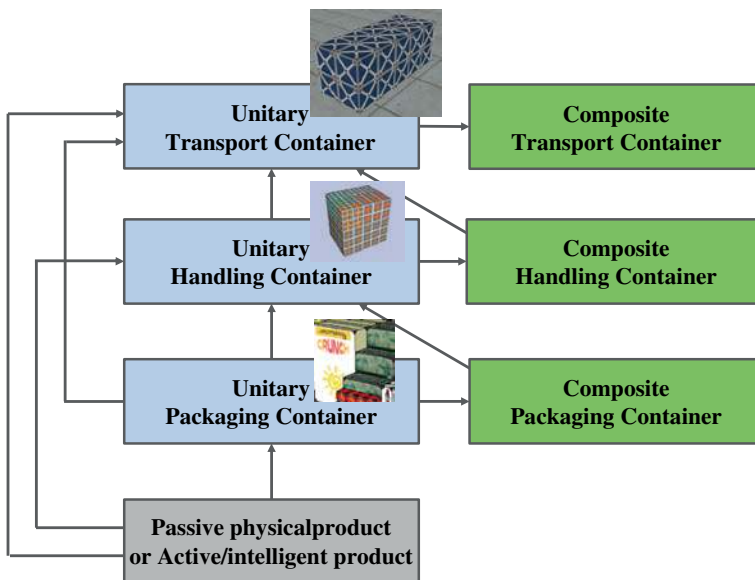


Fig. 1 Illustrating the relationships between the three categories of PI-containers

goods directly and/or PI-containers of smaller size. They have modular external dimensions on the order of 1.2, 2.4, 3.6, 4.8, 6 or 12 m. Sections with width and height both being either 1.2 and 2.4 m allow the T-containers to fit in current carriers.

- The **handling containers**, or H-containers, contain physical goods and/or PI-containers of smaller size. They are designed to be easily handled by PI-handlers (conveying systems, lifts...) and to resist rough handling conditions in the different nodes of the PI network. The typical maximal modular external size of an H-container allows it to fit into a T-container with external sides of 1.2 m. Available smaller external modular dimensions along the X, Y and Z axes are on the order of 50, 40, 30, 20 down to 10 % of this maximum size. H-containers are stackable at least 2.4 m high to fit in T-containers and PI-carriers (e.g. dry-bed trailers adapted to PI specifications).
- The **packaging containers**, or P-containers, are used to contain directly the physical goods. They are dimensioned to modularly fit in H-containers. As thin and light a possible, they are designed to be easy to insert and extract, to be able of protecting the product and to be stackable as necessary. They basically replace the typical custom packaging, for example designed to market goods. They offer easy customized panelling for marketing and informational purposes. They can be used to present the products in stores and to store the products at usage locations such as homes.

As depicted in Fig. 2, in a same category, the PI-containers can be composed and interlocked to build “composite” PI-containers and allow easier handling or transport, sharing the same standard type of interfacing devices.

The design of PI-containers is under study in two complementary interconnected fast-moving consumer goods (FMCG) logistics research projects. The European MODULUSHCA project focuses on the design of H-containers (termed

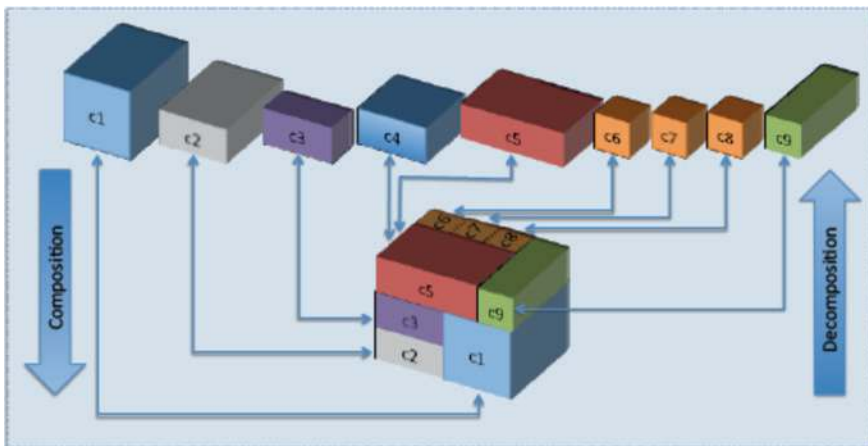


Fig. 2 Example of composition/decomposition of PI-containers

M-boxes in the context of that project), with the aim of building and testing physical prototypes of such H-containers [4]. The North American LIBCHIP project extends the design effort to encompass the three categories of PI-containers, up to the level of virtual prototypes [3]. In collaboration with these projects, the research exposed in this paper focalizes on the informational design of PI-containers, and more precisely on their intelligence design.

2.2 Informational Requirements

From an informational point of view, some requirements must be fulfilled:

- *Identification*: Each PI-container must have a unique worldwide identifier similar to the MAC access in the Digital Internet. This number is already defined by EPCglobal standard with the GRAI code for Global Returnable Asset Identifier [5, 6].
- *Traceability and tracking*: The PI-management systems must be able to locate each PI-container and to provide traceability information (e.g. status, arrival and departures dates in PI facilities, environmental conditions when necessary). Here also the standard exists with the EPCglobal BizStep and Global Location Number [5, 6].
- *Integrity*: The PI-management systems are responsible of the integrity of the cargo located in the PI-containers. For example, it implies obtaining information on the respect of the cold chain for perishable goods or on the opening of containers to prevent theft.
- *Confidentiality*: The content of a handling or transport PI-container must be known only by authorized parties according to their rights. These PI-containers must remain “black boxes” for the other actors of the PI-network. This implies data encryption and enhanced access right management.

The actual developments in sensor networks, wireless technologies, GPS and the increasing research effort in Internet of Things [7], cyber physical systems and intelligent products [8] offer the tools to support these requirements. In this context, the notion of PI-container activeness is introduced in the next section.

3 Concept of PI-Container Activeness

The concept of product activeness has been introduced by [9, 10]. Via an amplification of its informational, communicational and decisional capabilities, an active product is considered as an entity capable of interacting with the different support systems (e.g. manufacturing systems, supply chains, maintenance systems) during the successive phases of its life cycle.

Applied to the PI context, some communication, memory and processing capabilities can be associated to the PI-container to make it active so as to support the previously introduced informational requirements. A PI-container is then able to play an active role in the PI management and operations, contrasting with a traditional approach in which current containers are not able to take initiatives by themselves.

3.1 Brief Description of PI-Container Activeness

As mentioned in the introduction, Internet-of-Things related devices are undergoing a fast evolution in capability and costing. Currently, there are still implementation hurdles that would prevent implementing full activeness capabilities into PI-containers. So, a phased introduction of PI-container activeness is foreseen.

Early on, minimal activeness capabilities to be implemented include scheduled reporting and event triggering. With such capabilities, the container is able to identify its state and report it, compare its state with the desired one, and send information (e.g. warnings) when certain conditions are met.

In further stages, more complex capabilities can be installed, such as defining new goals and adapting current goals, communicating with other containers, negotiating with routing agents, and learning for individual and collective experience.

According to the different categories of PI-containers presented in Sect. 2, in further stages activeness is to ever more exploit interactions of a collective set of PI-containers on several layers, as well as with the other PI means and agents.

An example of three-layer activeness is provided in Fig. 3: a P-container #p containing several passive goods is placed in a H-container #h, itself contained in a T-container #t. At each layer, a PI-container can exploit different information sources to support its activeness:

- Proprioceptive information from information sources on the PI-container itself and on its cargo:
 - Embedded static or dynamic data associated to the PI-container (e.g. ID number, references of the cargo);
 - Measurements obtained via sensors on its own physical shell and skeleton (e.g. detection of shocks or of opening tentative) or on its inside physical environment (e.g., internal temperature), identified as 1 in Fig. 3;
 - Interactions with active PI-container(s) (often of lower categories) or “active” products that are encapsulated within its cargo (2).
- Exteroceptive information obtained via interaction with:
 - Its external physical environment (e.g., temperature, hygrometry) using sensors (3);
 - Other active non-encapsulated PI-containers, mostly of the same category (4);
 - The PI Management Systems (PIMS) in the wide sense, including means and agents (5).

In Fig. 3, the interactions denoted by numbers with the symbols ‘ and ’’ concern respectively the H-containers and the P-containers.

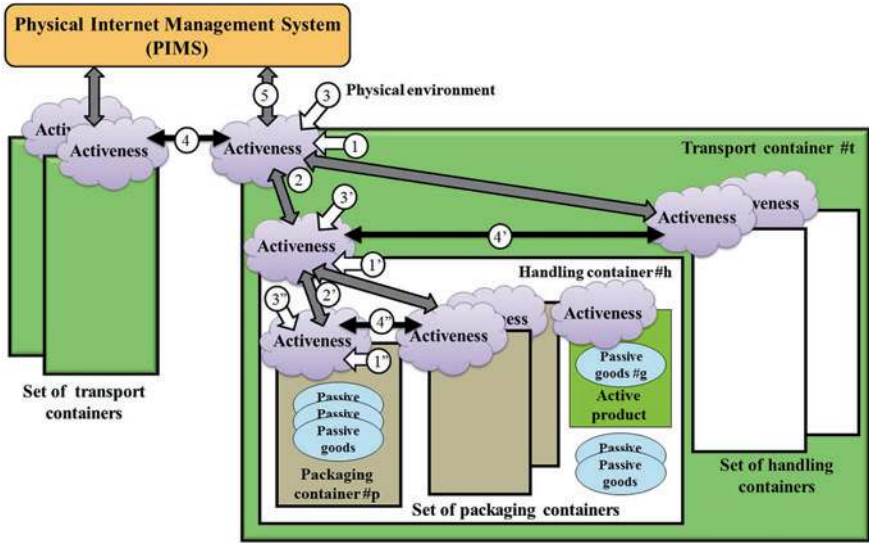


Fig. 3 Illustrating PI-container activeness

Interactions (2), (2') and (5) allow communication between the PIMS and a PI-container independently of its place in the layered hierarchy. For example, an alert generated by an encapsulated P-container #p must be transmitted to the PIMS through the two PI-containers #h and #t in which it is located.

Interactions (4), (4') and (4'') between PI-containers on the same layer are mainly used to exchange information on their respective contexts and allow reduction of false alarms. For example, a PI-container can compare its measure of current external temperature to the temperatures measured by the others nearby. In case of discordance on the measurements, no temperature alarm is sent to the PIMS but a signal is rather sent to have its temperature sensor controlled. In addition, according to the level of sensors equipping the PI-containers, some redundancies can be exploited. For example, in Fig. 3, the measures (3') from sensors concerning the exterior of the handling PI-container #h (e.g. temperature) can be compared with the measures (1) concerning the interior of the transport PI-container #t when both are active, aware of each other, and communicating amongst themselves.

The activeness of products contained in the PI-containers can equally be exploited if compatible with the transmission protocols used by PI-containers and the respect of access rights.

3.2 Classes of PI-Container Activeness

As outlined in [11], activeness must not be analysed as an all-or-nothing capability. It must rather be comprehended as being actionable function by function.

Indeed a PI-container can be “passive” for a function f_i and “active” for another function f_j . According to the analysis framework proposed in [11], four classes can be distinguished according to the role taken by a collective of PI-containers in the decisional process associated to a specific function:

- *Class 1* corresponds to a group of passive containers. The PIMS (often distributed through multiple agents) takes all decisions relevant of the function. It collects itself the information relative to the PI-containers and manages the entire decision-making process of the function based on the latest known state. PI-containers are only information carriers. Basic traceability or tracking functions are representative of this class [12]. The PI-containers are equipped with RFID tags or the likes, containing static or dynamic data. Data is read or written via readers located in the infrastructure of the PI network.
- *Class 2* characterizes a group of active PI-containers playing a triggering role in the decisional process, yet letting the other steps of the decisional process to be managed by the PIMS. Monitoring functions are typical of class 2. The PI-container equipped with adequate sensors can detect a problem (e.g. abnormal high temperature), check for detection integrity with nearby PI-containers when pertinent, and send an alert message to the PIMS. The latter is then responsible to deal with this situation and to find an adequate solution.
- *Class 3* is representative of a decisional process managed entirely by a group of active PI-containers. The PIMS and the PI infrastructure are only used to provide the services necessary to realize the function. The management of incompatibility between PI-containers is an example of function of the third class. This function avoids the proximity of containers carrying cargos incompatible with each other (e.g. chemical products that can contaminate each other or cause an explosion). As an example, when a PI-container arrives in a PI-hub, it sends to the PIMS the list of elements incompatible with its cargo. (For confidentiality reasons, the detailed composition of the cargo is not sent to the PIMS). After having checked with the other PI-containers in or moving toward the PI-hub, the PIMS sends in return a list with the identifiers of the PI-containers to avoid. Using this list, the concerned PI-containers can detect any incompatibility during their routing in the PI-hub and send alert messages to the PIMS.
- *Class 4* is characteristic of a self-organized collective. The active PI-containers are self-sufficient and are able to provide services that were obtained from the PI infrastructure in the previous classes. In [13], the authors exhibit a function of collision avoidance, relevant of this class. With the capability level of this class, during a routing process in a cross docking PI-hub, transport PI-containers having to book access to conveying modules could exchange with those modules and among themselves, without decisional interaction with the PIMS.

4 Current Issues for Research Works on “Active” PI-Containers

Two groups of research issues are induced when considering activeness of PI-containers, respectively from theoretical and technological perspectives.

First, from a theoretical point of view, research works must allow to:

- Characterize and assess the main benefits of activeness from the perspective first of the localized decision points, second of the current and next phases of the total product life cycle, and third of the supply chains through the interconnected logistics networks.
- Identify precisely the different levels of activities: identification, data support, communication and alarms sending or more complex activities (negotiation, learning).
- Provide an analysis framework allowing a detailed classification of the different activities.
- Provide guidelines to choose between embedded intelligence and remote intelligence. In fact, according to the function to be supported and the desired performances, the location of the intelligence is an important point to consider. Embedded intelligence allows taking into account more precisely the local environment but needs generally more costly equipment.

Secondly, from a technological point of view, research works must deal with the following issues:

- How to adapt activeness on demand? To adapt the level of activeness according the wishes of the PI users and the cargo value, the embedded informational modules must be adaptable or exchangeable. Indeed, different technologies (RFID tag, sensors, and embedded processors) must be added and removed easily to equip adequately the PI-containers according to the intended level of activeness.
- How to realize the physical integration in the container? Linked to the previous issue, it is crucial to study the physical integration of the informational equipment in the different types of PI-containers. Notably, for the Transport PI-container, the equipment must be able to face harsh environmental and handling conditions.
- Which type of transmission should be used to support the interactions between PI-containers? The retained technology must be able to support short-range data transmission (from one to several meters) in closed and/or open environments that are in general more controlled for the packaging and handling PI-containers.
- Which type of transmission should be used to support the interactions between PI-containers and PIMS? The retained technology must be able to support long-range data transmission, up to many kilometres, for transporting PI-containers, while for the other types the need for long-range transmission depends on the fact that it is to be relayed through the technologies of the transport PI-containers and carriers encapsulating them.

5 Conclusion

In the innovative field of the Physical Internet, the design of efficient PI-containers constitutes a cornerstone. This exploratory paper started by an overview in the field of the PI-container design, with an emphasis on the requirements attached to the design of PI-containers. Then it proposed the notion of PI-container activeness. Following a brief presentation of the activeness concept in general, it has then fleshed it in the Physical Internet context, notably through a four-class characterization of activeness capabilities. Finally, several research issues in the field of active PI-containers have been proposed.

If the current European project Modulushca [4] can be considered as a first step in the design and prototyping of PI-containers, focused on the handling PI-containers, some important research efforts must be realized in the next years to build active PI-containers capable of operational autonomy and interaction in a wide range of industrial applications. Priority is expected to be first on transport and handling PI-containers, with packaging ones being tackled as cheap small enabling technologies become available. The authors' research teams are cooperating to refine the concept of PI-container activeness in a French ANR funded research project, called PI-NUTS, focused on Physical Internet cross docking hub control system.

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