Applications for Frugal Product Customization and Design of Manufacturing Networks

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Abstract

Manufacturing is moving towards a new era of frugal innovation, exploiting customization and regionalization practices, where companies base their business on mobility and on adapting local market requirements, resulting to a new business model through low-cost and high customer value solutions. Mobile applications and advanced decision-making tools are becoming more and more necessary in order to address individual needs and preferences of customers and markets, in general. Towards that end, this paper presents a framework that consists of a mobile application supported by augmented reality technology, and a manufacturing network design tool supported by a smart search algorithm. The proposed framework aims to support the customer integration in the product design phase and, consequently, in the design of the manufacturing network. The proposed work is validated in a white-goods industry.

Keywords: Customization; Regionalization; Frugal; Design; Manufacturing Networks;

1. Introduction

Modern companies, in the context of global competition, in order to maintain their market share rates and also reach new markets, should re-shape their strategy by taking into account the needs of the different regional markets. Customer integration in product design [1], considering multiple regions, is a promising step towards capturing the market’s pulse and new ideas on product design provided by the customers themselves. This leads to regional characterization of customer demands and product requirements. In order to address these challenges, Original Equipment Manufacturers (OEMs are searching for new approaches to create well-structured manufacturing networks with higher efficiency, moving towards a more close-to-customer approach [2]. This combination of global production and distributed customer networks forms the basis of frugal innovation. Frugal innovation exploits the concept of intelligent use of resources, developing products for specific markets with optimal cost and quality [3].

The Information and Communications technology enables the use of mobile devices and the distributed decision-making [4] which can form the basis of the dissemination of the frugal innovation concept. The use of mobile applications is an enabling technology capable of supporting the ubiquitous access to data and integrating the customer and their needs in the product design process. More and more companies are starting to base their business on mobility and on distributed decision making [5, 6] in order to target and reach new markets.

Motivated by the need to support the companies to move towards frugal innovation and design, the proposed work presents a customer-oriented mobile application that provides the ability to configure the customized product using Augmented Reality (AR). In addition to that, the proposed work presents a smart decision-making algorithm for the manufacturing networks design that uses as input the different product configuration provided by potential customers of emerging and developed markets.
2. State of the art

Following the main objectives of the research work, the literature review is clustered into the following topics.

2.1. The frugal innovation concept

The frugal innovation concept aims at introducing new business models in order to reduce the complexity and the total life-cycle costs while providing high value and affordable solutions for customers of emerging and developing markets. [7]. Frugal is defined as: Functional, Robust, User-friendly, Growing, Affordable and Local, and can be found in many industries [8]. There are numerous examples of frugal innovation outcomes in the industrial sector, including cars, refrigerators, as well as power systems [9]. The previously mentioned outcomes are produced by the unique needs of the customers of the different emerging markets. Several research works have already pointed out the importance of frugal innovation and the fact that it can produce sustainable solutions and results [10, 11]. The innovative combination of existing technologies and tools supported by the Information and Communication technology will assist the companies to address the economic, social, and environmental challenges.

2.2. Product Configuration through Web and Mobile applications

Customer integration through mobile applications in the design phase can increase customer satisfaction by considering their needs. Online product configuration has been investigated by Chen in [12], including a web-based software prototype, where household consumers can customize products using linguistic description. A more recent approach for online customization was proposed approximately 8 years later by Chryssoulou [13], presenting a virtual/augmented reality environment for collaborative product review and customization. As a next step, Mourtzis et al. presented an online 3D product personalization, the product being a car [14].

Taking the aforementioned solutions, a step further, customer-oriented apps have been developed and have been reported in literature. The use of the mobile application and the customer integration in the design phase provides the OEMs access to geolocation, user profiles, regional options, and supports them to re-design their products for new markets [15]. In addition to the above, mobile applications supported by AR technology is a novel approach; therefore, only a few consumer-oriented apps supported by AR have been reported in the literature. Common functionalities on this field include visualization of a product from a catalogue in the customer’s accommodation (IKEA) [16], fulfilment status and typical visualization of products of a catalogue (Sandvik) [17].

2.3. Manufacturing Networks design and planning

Online product customization and personalization following regional requirements will enable OEMs to easily and effectively target new markets. OEMs should consider new decision-making and decision support systems for the manufacturing networks design and planning [18] in order to produce new configurations of their product and quickly release them with a low cost to the new markets.

Numerous decision-making systems have been reported in the literature, especially focusing on a mass customization environment. A decision-making method that supported the selection of colour combinations for customized products was proposed in 2007 [19]. Another work conducted in 2005 utilized a Case-based reasoning technique in order to generate an accurate Bill of Material (BoM) that fits in individualized situations [20]. In the field of mass customization, a new approach for decision-making was introduced by Mourtzis [21]. This work introduces an investigation on the performance and viability of centralized and decentralized production networks under heavy product customization. In addition to that, in 2014, an approach for the design of the manufacturing networks for mass customization, using an intelligent search method, was presented [22].

Moving from the era of mass customization to the era of regionalization, a few literature works have been reported. An approach for customer-driven planning and control of global production networks considering regional requirements is presented in [23,24]. Moreover, a decision-making method which utilized a smart search algorithm considering criteria like locality, frugal lead time, as well as production cost and quality was presented in [2]. New criteria that can support the decision-making and can take into account regional requirements were introduced in this work, moving towards frugal innovation.

2.4. Remarks and Contribution

Existing examples of frugal innovation emphasizes the frugalization great potential [25]; nevertheless, industrial applications appear as fragmented and far from being structured. This asks for business approaches, which are able to provide locally adaptable offering, without loses in terms of efficiency, in a systematized manner [26]. To achieve that, new product-services, related advanced ICT and cloud-based tools for supporting frugal innovation should be developed, allowing the co-evolution of products (and services)-processes-production systems, according to localized customers’ needs and production sites capabilities [26]. The suggested approach contributes to the research on the field of frugal product customization and design of manufacturing networks. A product configuration application supported by AR technology and capable of capturing the different regional requirements of the different targeted markets is introduced. Following the new product configuration and the possible re-design of the products for a new market, a smart decision-making algorithm is utilized in order to support the design of the new manufacturing networks efficiently and quickly. Addressing the main challenges of designing the appropriate products for each market and selecting the optimum suppliers based on their suitability and availability, the proposed work aims at introducing the smart use of resources in order to move towards frugal innovation.
3. Proposed Framework

The overall framework and workflow of the proposed framework is depicted in Fig.1. The proposed framework consists of two main components, with a main purpose to shift modern industries towards frugal innovation by taking into consideration regional customer requirements and smart use of resources. The first component, the AR product configuration tool, provides the industrial companies with the ability to target new markets, developed or emerging, and re-configure and design new products based on the meaningful information gathered by the regional customers.

The second component is a decision support tool for manufacturing networks design. Once a new product configuration is defined for a new market, the industrial company has to quickly and effectively design the new network. The proposed decision support tool utilizes a smart search algorithm capable of generating and then evaluating alternative manufacturing networks in order to select the optimum solution, taking into account defined criteria by the industrial company.

3.1. Product configuration using AR

The entry point of the proposed framework is the product configuration tool which aims to enable the integration of the customer in the design phase of a product. It is utilized by the industrial companies, and especially by OEMs, in order to capture the pulse of a new targeted market. The proposed tool will provide a great advantage to OEMs, as they are capable of gathering data related to customers’ regional requirements and design a new or re-design an existing product in an efficient way. In this way, OEMs and industrial companies in general will remain competitive by delivering products that conform to the market needs. The proposed application enables OEMs to gather meaningful knowledge that will empower them and to strengthen their position in the globalized market region.

The developed product configuration tool is designed in order to be user-friendly and easy-to-use. The use of the Augmented reality technology and its functionalities provide the end user/customer with the ability to edit features of the product such as selection of Product components, selection of colours and materials, selection and addition of new components and features based on company constrains (LCD monitor, water dispenser, brackets, etc.) and visualize the refrigerator in the physical environment (e.g. kitchen).

The AR offers advanced visualization and editing functionalities for allowing “design-by-non-designers” [27] (Fig 2). Moreover, it provides the opportunity to the customer to visualize the product in their actual size, inside customer’s environment, thus evaluating its appearance and functionalities while viewing its interaction with the other products in the same space.

Once the customer logs into the AR mobile application, they should provide information related to their profile. They would be offered the option to select from a variety of different roles, including among others consumer, country manager as well as region manager. As a next step, the customer provides some further information including age, family size, level of education, as well as income. Once full profile information has been provided, the customer proceeds with the product customization.

All the above data are collected by the OEM, and meaningful information is generated utilizing algorithms for data analysis.
The AR module has been developed as a standalone application for Android OS running devices. Through the proposed mobile application, the marker can be sent via email to the customer. The available features for configuration and the customization options, in general, are constrained by the OEMs due to manufacturability and branding issues.

3.2. Frugal Manufacturing networks design

The new product configuration, which is based on the regional customer’s demands and requirements, will trigger the decision support tool for the manufacturing networks design. Following the new product configuration consisting of new regional and frugal components (low-cost), various suppliers should be considered in order to address the customer requirements. Multiple and different suppliers from different markets are taken into account.

One of the main challenges during the supplier selection and the supplier networks design is to select the optimum supplier based on their suitability and their availability. Therefore, the proposed work suggests a smart search algorithm capable of creating subsets out of the total number of alternative manufacturing network configurations by utilizing three adjustable parameters [28]. The three control parameters that are utilized are the maximum number of alternatives (MNA), which controls the breadth of the search, the decision horizon (DH), which controls the depth of the search, and the sampling rate (SR), which guides the search towards the high quality branches of the tree of alternatives [29]. The optimum values of these factors will be obtained through a statistical Design of Experiments (SDoE) [30]. The proposed smart search algorithm consists of six main steps: (i) determination of criteria to satisfy objectives, (ii) definition of criteria weights, (iii) formation of alternatives, (iv) calculation and normalization of criteria performance, (v) calculation of utility value, and (vi) selection of an alternative with the highest utility value [26, 29, 31] (Fig. 3). Multiple and conflicting criteria are considered and are calculated by the smart search algorithm also during the decision making procedure. Production and Transportation Cost, Quality, Lead time, are among the main criteria considered [28]. To address the need of frugal innovation in the context of the supplier’s selection method, the locality of the suppliers is also considered as a main criterion. Locality shows how close the supplier is to the targeted market. Locality as a criterion in the manufacturing network design has been introduced by Mourtzis et al in [2].

The total performance of the networks is calculated by measuring defined KPIs. In that stage, targeted values of KPIs suggested by industrial companies are taken into consideration during the evaluation of the produced manufacturing network. The proposed work presents an overall framework that can support frugal innovation adoption from manufacturing companies. Through the proposed approach, several main aspects of frugal innovation are considered including locality, affordability, user-friendliness, as well as growing aspect. The first part of the proposed framework, the AR product configuration is capable of gathering the regional customer requirements in an easy-to-use and user-friendly way through the opportunity to visualize the product in their actual size, inside customer’s environment. In addition to that, the network design tool considers the aforementioned requirements and is capable of generating feasible, low-cost networks considering also local suppliers. In general, the proposed framework supports manufacturing companies to move towards frugal innovation and to target new easily and efficiently.

4. Software implementation

The AR application was developed with Unity 3D™ [32] and Vuforia™ SDK [33], a set of plugins for Unity 3D™ that allows users to easily develop and deploy AR applications. (The Vuforia™ SDK was used for the connection of the AR model with the customized marker using image recognition.) Specifically, The Vuforia™ SDK was used for the marker recognition and marker tracking using image recognition. The decision support tool for manufacturing networks design was designed as a web-based module using the Java™ programming framework. A Relational Database Management System (RDBMS) has been implemented using the Oracle 9i Database.

5. Case study and Results

The applicability of the proposed methodology in a real industrial context is currently being tested on a major white-goods industry that is moving towards frugal innovation. The pilot application focuses on a typical production engineering scenario, where the OEM targets a new market and needs to get the pulse of that market and re-configure existing products or design new ones. Moreover, once the new product has been configured, the OEM needs to quickly and efficiently find a new manufacturing network in order to produce and deliver the product in optimum cost and time. The current procedure that is followed by the industry is performed through phone calls or excel-based solutions, without considering a structured and automated procedure. The proposed ICT-based solution is developed in order to support the current procedure and provide the company with a structure and an automated way to target a new market and produce and deliver their products in optimum cost and time (Fig. 6).
The AR product configuration tool was provided to the market as an application, through the OEM main website and Google Play Store. Moreover, through the OEM main website, the customers were able to receive by email and print the marker in order to use the AR application. Different roles were offered as options, including consumer, country or region manager. Following their regional requirements and their experience on the provided product by the OEM, in this case a refrigerator, they provided their input and their configurations (Fig. 4).

The new product configuration is decided by the OEM based on the received feedback and the various product configurations submitted by the customers through the AR application. The OEM utilizes the decision support tool, including the smart search algorithm, in order to generate the different, alternative manufacturing networks that can produce and deliver the new product. Through the proposed search algorithm, the different alternatives are evaluated based on the defined criteria by the OEM experts. In this case, the considered criteria are the lead time, the total production and transportation cost, the total quality, as well as the locality of the suppliers. Following the aforementioned scenario, the AR product configuration tool was provided to a new market in order to capture the market pulse and define a new product configuration of the provided refrigerator.

The new product configuration triggered the manufacturing network design tool, which took it as input and generated alternative network based on the defined criteria by the industrial experts. The final configuration of the network and the results are presented in Fig. 5. Following the feedback received by the industrial experts, the proposed framework and the developed tools are capable of supporting the company to move faster and more efficiently to the frugal innovation area.

Conclusions

The presented framework allows and enables OEMs to reach new markets in a quick and efficient manner, to design products that will fulfil the regional market requirements, and to release low-cost the products in a short delivery time.

The AR product configuration tool will enable the integration of the customer in the design phase of a new product or in the re-design phase of an existing one in order to address the needs of the market. The AR application is designed to retrieve a multitude of information from the customers, who would be offered the option to assume different roles (consumer, country or region manager). Based on the level of knowledge and experience of each role as well as on their regional needs, the OEM will be able to target new markets and to receive meaningful information. Moreover, customers strengthen their perception of the product and they become an active part of the manufacturing network as their configurations influence the design of the manufacturing network.
The integration of the AR product configuration tool along with the decision support tool proposed in this work, both empower the OEM to design efficiently and in a cost-effective manner their manufacturing networks. The proposed multi-criteria search algorithm can quickly examine the produced solution space and is capable of providing high-performance networks targeting the best ones. In the above, the proposed methodology will shift the design of the products and the manufacturing networks towards frugal innovation, as different customer requirements, both regional and frugal, are considered. Moreover, through the proposed decision making tool, optimum manufacturing networks that turn the related constraints into advantages and driving forces towards product innovation are generated targeting the optimum cost and time.

Future work will be focused on testing the performance of the proposed methodology in other industrial case studies, thus enriching the proposed method with extra functionalities. In addition to that, a data analysis algorithm to expeditiously analyze the data obtained from the customers through the AR product configuration tool will be explored.

Acknowledgements

The work presented in this paper is partially supported by the European Union’s Horizon 2020 research and innovation project “Customer-driven design of product-services and production networks to adapt to regional market requirements- ProRegio” (GA No: 636966).

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