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Study into the potential of UWB applications in the process industry

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STUDY INTO THE POTENTIAL OF UWB APPLICATIONS IN THE PROCESS INDUSTRY

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Abstract

The advances in mobile technology, such as ultra wideband (UWB), enable the use of advanced applications in the process industry. The main challenge in the first phase of designing UWB networks and applications is getting to know what the process industry, i.e. the potential customer, wants. In this paper we present how we applied a user requirements elicitation process to get information about the expectation from the process industry regarding wireless networks and more specifically ultra wideband. We describe the design process of the balanced decisions that have to be made regarding these elements, i.e. applications as demanded by the process industry, the technology as offered by the ICT industry and the value network that has to guarantee benefits for all involved partners. The outcome of this feasibility study leads to the decision for going on with the next step, i.e. the design and building of an UWB testbed.

Keywords: Design, User requirements elicitation, UWB, Process industry

1 INTRODUCTION

The emergence of commercial wireless devices based on ultra wideband radio technology (UWB-RT) is widely awaited and anticipated (Hirt 2003). UWB engineering efforts started already in the end of the 1970s but were recently boosted because the Federal Communications Commission (FCC) allowed UWB-enabled devices to overlay existing narrowband systems (Foerster et al. 2001; Scholz et al. 2005). A growing interest within the wireless industry as well as within academic and other research institutes in the US and in Europe can be noticed (Hirt 2003). The regulation by the Federal Communications Commission (FCC) and the European Commission (EC) is still in progress but nevertheless the question ‘which will be the so-called “killer” application’ has presented itself (e.g. Scholz et al. 2005). We argue to follow a design approach instead of waiting on accidentally discovered killer applications and started a research program to design UWB applications.

UWB can be applied in different domains and the process industry opens up interesting possibilities. The research presented in this paper concerns a feasibility study for novel UWB applications in the process industry. First meetings with stakeholders of this industry led to the impression that the characteristics of the UWB technology suit their environment quite well. However, since the technology is new and not proven yet it is not possible for the industry to assess the value of this technology for them. This is an ever returning issue in situations when new technologies are rising. Furthermore a network of actors is involved in the development of UWB applications. A consortium of partners with their own know-how and expertise is needed for a design project such as this. In the design project, all the time trade-offs have to be made between the technology, the user requirements and the organizational issues. In this paper we describe the first phase of these trade-offs, i.e. the analysis phase of the design process.

2 DESIGN APPROACH

The primary measure of success of a designed system is the degree to which it meets the purpose for which it was intended. However, requirements are difficult to elicit because individuals must express their needs in natural language, which is subject to ambiguity at the best of times, and furthermore there are mostly many individuals involved who cannot oversee the whole (Sallis et al. 1995). Requirements engineering is the process to discover the purpose of a system and this is a highly collaborative process that involves many stakeholders: the customer who pays for it, the user who interacts with it, the developers, to name a few. Much research has been carried out on the use of Group Support Systems (GSS) to support and improve the process of requirements engineering (Boehm et al. 2001, Grünbacher et al. 2001, Briggs et al. 2003). Two things that come forward are that most GSS-based approaches focus on communication of and agreement on requirements only, and leave out the other steps on eliciting requirements, modeling and analyzing, and evolving requirements. Secondly, in order to have a reproducible, repeatable approach based on GSS three aspects should be addressed: the tool, the configuration, and the script (Briggs et al. 2003). These concepts are relatively new and most research on the use of GSS for requirements engineering do not yet use these concepts explicitly, or implicitly. So far, the GSS use is subject to multiple interpretations by various users (Gopal et al. 2000). To deal with this, den Hengst et al. (2004) presented a repeatable GSS process for eliciting requirements to derive user requirements.

In this paper, we build forward on this repeatable GSS process to get requirements. Furthermore, these requirements have to be considered in the light of the still evolving wireless communication technologies, like UWB technology. This makes the match between the enabling technology and the requirements of the users more difficult. The third element in the design process is the network of involved actors who have to collaborate to explore and exploit the UWB applications. This is not an assignment for only one organization since researchers, the process industry, system integrator(s), application developer(s) etceteras are involved.

Van de Kar (2004) put together these three elements, i.e. the network of involved actors, the enabling technology, and the service/application formula, in a management led innovation design approach. The leading principle of this approach is that the three mentioned elements have to be balanced in each phase of the design process, i.e. the analysis, preparation, synthesis, implementation and test phases.

The focus of this paper is on the analysis phase which should result in design decisions regarding the value network, the enabling technology, and the service/application formula; see Figure 1.

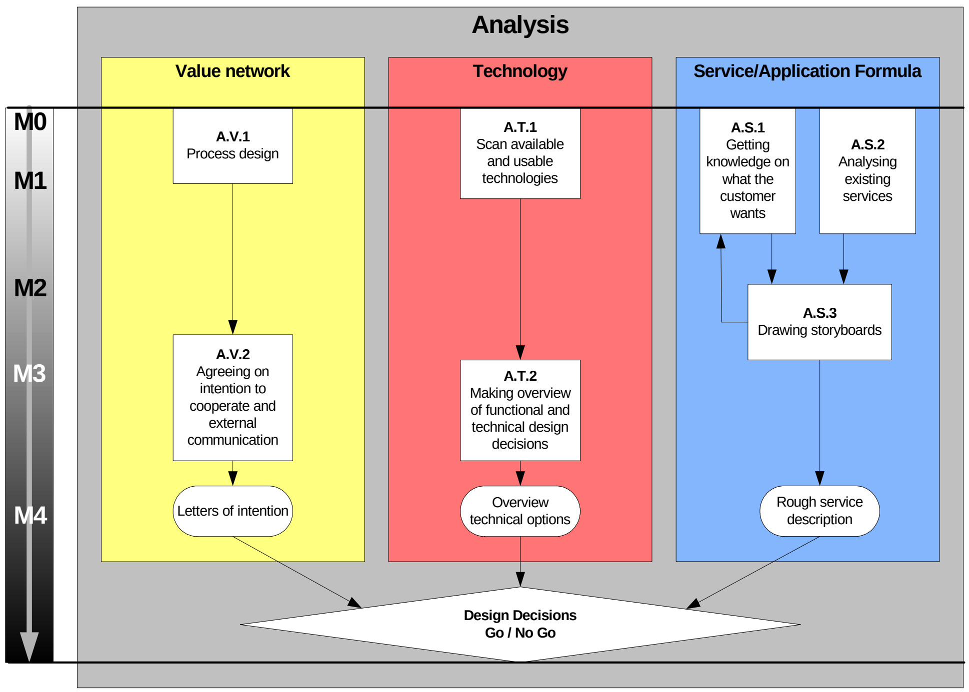

Figure 1. Analysis phase (van de Kar 2004)

2.1 Design of the value network

The analysis starts with the design of the process aimed at designing a new application or service (see Figure 1, activity A.V.1). The design of the process is especially important in the creation of the network organization. Especially in the world of new ICT applications various firms have to cooperate to develop and launch a complete service or application as demanded by customers. We define the value network as “the configuration of activities between organizations and the correlated relationships, revenue models and cost structures”. It is recommended to take sufficient time to make process agreements with the involved parties consisting of the four core elements openness, protection of core values, speed and substance as this prevents problems later (de Bruijn et al. 2002).

Moreover, at the point that actors express their intention to participate it is necessary, and important in this early phase, to make clear what information is confidential and what can be made public (Figure 1, activity A.V.2). It is also necessary to agree on which actor is going to communicate what externally including to the press. In innovation projects, agreements on confidentially and communication have to be made at the start. The result of the value network activities in this phase should be signed letters of intention with partners.

2.2 Design of the technology

In general a distinction can be made between technology driven and market driven development of applications. The design approach should start with the targeted user's context in an ideal situation. However, since the applications as considered here, are driven by the technology that enables these services, it is necessary to investigate the availability of technologies that are reliable and robust enough to function as an enabler (Figure 1, activity A.T.1). Based on the output of activity A.T.1, the initiator will have ideas regarding the available technology and its functionalities. Thus the outcome of this activity also sets the boundaries for how advanced the application will be. The next activity is making an overview of the decisions that have to be made related to the available options (Figure 1, activity A.T.2). The result concerning the technology should be an overview of the technical options that can be discussed with the intended partners to reach the aimed application formula.

2.3 Design of the application formula

Asking potential customers for their wishes with regard to applications which are out of the scope of the normal operation, is a real challenge. In earlier research Den Hengst et al. (2005) found that Group Support Systems GSS can be used to design a repeatable process for user requirements elicitation and proposed the following repeatable process for user requirements elicitation (Figure 1, activity A.S.1).

- Participants to invite. Selecting and inviting the participants is the first step for analyzing user requirements. GSS have been found to effectively support large groups (more than 8 members) (Dennis et al. 1990). The participants need to be reasonably knowledgeable about the topic and should be interested in talking about it. They should be comfortable in talking to each other, but over-familiarity might have a negative effect on the results. Furthermore, the group should not include too many different types of people.
- Basic meeting activities. Briggs et al. (2003) have identified seven basic activities in a group process: divergence, convergence, organization, elaboration, abstraction, evaluation and building consensus. These basis steps are used to design the design process and compared with literature on focus groups (Bruseberg et al. 2003). To conclude, the steps to be carried out are: (0) warm-up, (1) problem analysis based on current daily experiences, (2) solution generation based on those experiences, (3) demonstration of future scenario's, and (4) redefinition of solutions based on this.
- Techniques to use. Briggs et al. (2003) propose ThinkLets as an approach to produce far more predictable and repeatable results of group sessions. Thinklets describe in detail how a certain activity can be realized. To come up with the key problems of the participants, three thinkLets are used: FreeBrainstorm (Divergence), FastFocus (Convergence), and BroomWagon (Convergence).

Den Hengst et al. (2004) calculated that this user-requirements-elicitation GSS session takes about 3.5 hours based on a group size of 15 participants. With more or less participants, the time schedule should be adapted. Based on the output of the GSS sessions and the analysis of the existing applications (Figure 1, activity A.S.2), professionals add their knowledge, expertise and creativity to develop storylines (Figure 1, activity A.S.3). Model techniques originating from product design theories are helpful here.

2.4 Results of the analysis phase

We explained the design activities and what the results of the analysis phase should be for the three elements: value network, technology and service. However, the essence is to have these three elements in balance and therefore tradeoffs have to be made. The first trade-off concerns the service formula and the technology: 'How can we get the enabling technology to support an application that fulfils the demand of the users?' The second trade-off concerns the technology and value network 'How can we get a value network in place to provide the necessary technology?' The third trade-off concerns the value network and the service formula 'How can we create a network of actors and coordinate the activities of these different actors to deliver value to the user?'

In the next section we explain how we dealt with this in a feasibility study for an UWB testbed.

3 CASE: A FEASIBILITY STUDY FOR AN UWB TESTBED

The start-up firm Utellus started its business to develop protocol stacks for mobile ad hoc networks (www.utellus.nl). Ultra wideband was chosen as the underlying robust radio technology for its promising functionalities. Utellus approached Delft University of Technology to do a feasibility study on UWB applications in the process industry summer 2004; the Faculty of Technology, Policy and Management (www.tbm.tudelft.nl) since it has experiences with design approaches for mobile services and the Faculty of Electrical Engineering, Mathematics, and Computer Science (www.ewi.tudelft.nl) for its research experiences on digital processing and algorithm development for UWB-radio, wireless ad-hoc networks, network protocols, radio transmission and UWB technology. These three partners started a feasibility study to investigate whether and how a UWB testbed should be developed. This feasibility study took place between September 2004 and April 2005.

The case study description is structured along the design activities for the three elements 'value network, the technology, and the service formula' as mentioned above in section 2.

3.1 Value network

The first step in the process to design UWB applications was a meeting of the startup firm Utellus and research from Delft University of Technology to discuss the idea to submit a proposal for getting subsidy for a feasibility study to build a UWB testbed. Knowing roughly the characteristics of UWB technology led to the idea to focus on the idea to develop UWB applications for the process industry. The actor scan pointed at the investigation of the wants and the needs of the process industry for wireless applications.

We found that communication networks are widely used for automation purposes in the process industry. They are the subject of rapid developments in technology and software. The choices for the architecture of the automation profile can be different: in some cases the local area networks between office and factory make sense; sometimes integrated distributed control systems are preferred over simpler more decentralized personal-computer-based systems. Modern automation systems provide possibilities for fitting a combination of centralization and decentralization, so this combination is often the best choice. The industrial automation field has recently experienced the adoption of wireless networks solutions in these systems (Dinesh et al. 2005; Ilyukhin et al. 2001).

In particular the areas of Manufacturing Execution Systems (MES) and Control Systems are expected to be the most promising opportunities for wireless application for the communication networks in the process industry. MES consist of plant-wide information systems providing information that enables the optimization of manufacturing activities from order launch to finished products. Control Systems are usually hybrid hardware/software systems such as DCS (Distributed Control Systems), PLC (Programmable Logic Controllers), SCADA (Supervisory Control and Data Acquisition) systems and other computerized process controllers. For each MES or Control operational function there is a range of feasible automation degrees. For this batch-wise type of industry, where flexibility is an important issue, wireless communication can also be an appropriate solution.

The involvement of the users/customers from the process industry, varying from plant managers of a batch factory to automation engineers, forms a necessary condition for a successful feasibility study. The quick scan of the configuration of involved organizations at the start of the feasibility study is drawn in Figure 2.

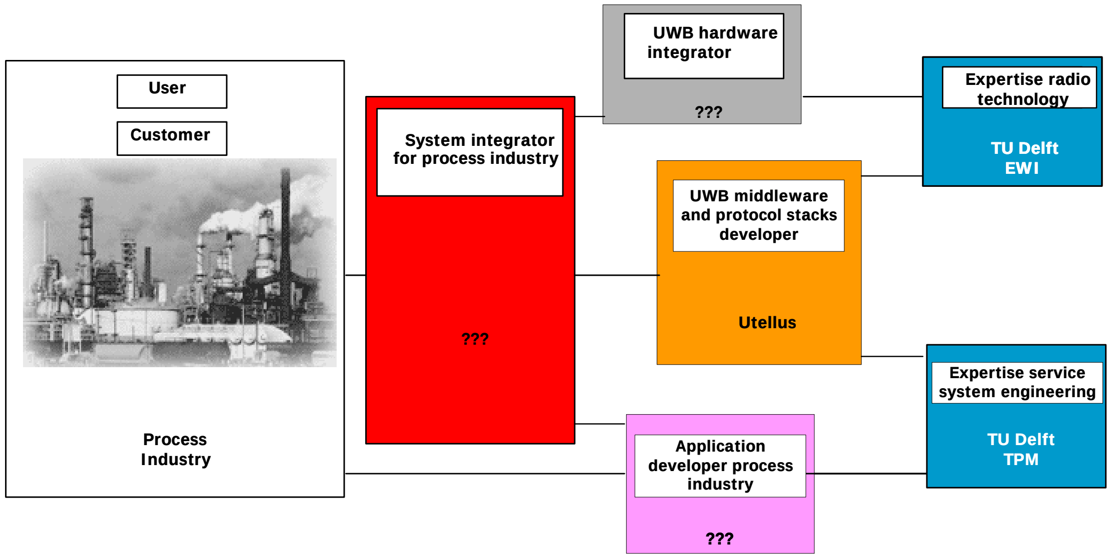

Figure 2. Intended partners for the UWB RT testbed consortium

The three mentioned partners (Utellus and the two faculties of TU Delft) decided to cooperate in the feasibility study and to use this study to find the lacking partners. In this research industrial partners were involved from the very beginning of the study.

3.2 UWB RT technology

The occasion of this feasibility study is the rise of a new technology, i.e. Ultra wideband radio technology (UWB RT), and in that sense it is a technology push project. UWB belongs to the family of the wireless networks together with radio technologies within the IEEE 802 family and Bluetooth [see Porcino et al. (2003), and Roy et al. (2004) for an overview].

Comparisons in Foerster et al. (2001) indicate that the spatial efficiency of UWB systems (estimated at 1 000 000 bits/second/square meter) far exceeds efficiencies of systems based on the IEEE802.11a Standard (estimated at 83 000 bits/second/square meter), Bluetooth (estimated at 30 000 bits/second/square meter), and the IEEE802.11b Standard (estimated at 1000 bits/second/square meter). Capacity calculations for Additive White Gaussian Noise (AWGN) channels support this assessment (Scholz et al. 2005). Porcino and Hirt (2003) conclude that “UWB-RT has the potential to become a viable and competitive wireless technology for short-range high-rate Wireless Personal Area Networks as well as lower-rate and low-power-consuming low-cost devices and networks, with the capacity to support a truly pervasive user-centric and thus personal wireless world”.

On the basis of our study of the future demands for communications in the process industry, one may conclude that the sector does have a huge interest in new radio technologies offering opportunities for “freely moving”, very low power wireless communications. The application for such new radio technology will be in “indoor plants” as well as on open air wide-area factories and industry plants. Basically the new communications must satisfy the following demands:

- Support of communications of persons or groups of persons active in the plant at any place or any location. In addition there can be a centralized control on the communications.
- The new technology must be a vehicle for a new generation of ubiquitous wireless, telemetric communications, offering possibilities to connect sensors and actors on a flexible (plug and play) basis using flexible ‘ad hoc communication’.

- The system must have sufficient performance (bandwidth) to support applications such as visualization of data (e.g. measurement data, process information, showing pages of instruction manuals).

The conclusion of the UWB-technology scan is that it can play an effective role in the telecommunication and telemetry needs in this specific application area. In addition we were able to conclude that UWB can offer extra facilities not offered by current available techniques. The aimed advances of UWB are: 1) low energy, 2) localization features and 3) realization of flexible infrastructures.

3.3 Application formula

An important activity in the research was a GSS session to get more insight in the wants and needs of the process industry regarding wireless networks. The objective of the group session was twofold. First, we wanted to know in what kind of situations the customers foresee advantages of wireless networks. We did not ask the customers to come up with wireless applications since not every potential customer knows about the technical possibilities of wireless applications. Instead we asked them for the areas that they currently encounter in the process industry as potential areas to use wireless networks. A prioritization of these areas should give insight in the potential use of applications on wireless networks. Secondly, we wanted to know what criteria potential customers use for selecting a certain application for these areas by elaborating on the effect of the possible applications by means of UWB technology. We described the session by specifying the participants we invited, the activities and techniques we used, and the results.

The participants to invite. The 14 participants were people working in instrumentation and automation departments in the process industry and their suppliers. Four researchers involved in the feasibility study were present to provide extra information if needed. They did not actively participate in the brainstorm session. The participants were selected based on their knowledge, interest, representing a wide range of companies from the industry and their suppliers and willingness to participate. Access to these participants was provided by personal contacts of Utellus, the researchers, and the 'International Instrument Users' Association’ (WIB; www.wib.nl). This is an organization that evaluates process instruments for their members. The chairman of WIB was also present at the GSS session. The invited process industry participants had functions like plant manager, instrumentation or process automation specialist and worked in companies from the chemical and food industry, i.e. Shell, Dow Chemical, Dupont, Exxon, Heineken and Unilever. Participants from the process industry suppliers were equipment builders and project managers for plant building from companies, i.e. Enraf, Controlec and Produca.

The activities and techniques used. The session was to a large extent structured conforming the GSS session for user requirements elicitation as described in section 2. The outline of the session is presented in Figure 3 and below we describe what we did including how it deviated from the original outline.

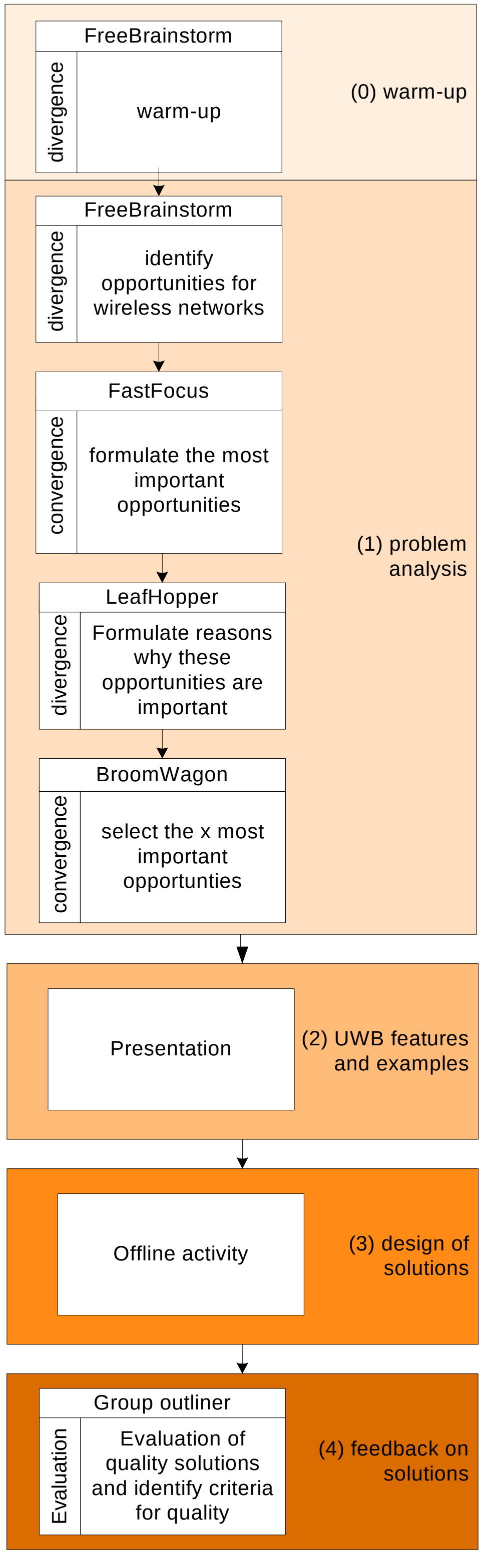

Figure 3 Layout of the GSS session

- The brainstorm started with the question to spout ideas for wireless network opportunities (see FreeBrainstorm to identify opportunities for wireless networks in Figure 3). This means that there was not first an activity to select important problems and then brainstorm about solutions on the problem but that we immediately started with the solutions. The reason for this is that the participants were experts who are looking for specific solutions. However to keep an open mind we explicitly asked about wireless networks opportunities in general and not for UWB technology specific in this phase of the process. The participants typed about 200 ideas of which 28 were left after the convergence activity (Fastfocus in Figure 3).
- After formulating the 28 most important opportunities we did a divergence activity that was not in the original scenario. The participants were asked to formulate reasons why these 28 opportunities were important for them. We did this extra activity because the project team members wanted to have this extra information for the requirements analysis (Leafhopper in Figure 3).
- The participants voted for the x most important opportunities after this extra divergence activity and before the UWB presentation (BroomWagon in Figure 3). Nine ideas got four or more votes. Two of them could be combined so we ended with the seven most important opportunities for wireless networks in general.
- A presentation on the features of UWB followed with examples. Questions of the participants on the promising functionalities were answered by practitioners from Utellus as well as researchers from the university.
- In pairs of two the participants elaborated offline on the context, idea of the application and effect of the application for the top seven opportunities (Offline activity in Figure 3).
- The solutions were presented and during these presentations the other participants and the experts typed in the GSS system their comments and ideas (Group Outliner in Figure 3).
- The session ended with an evaluation.

In total the session took four hours.

Result of the session. The seven most important opportunities that were worked out into solutions by the participants (see appendix).

After the session, these seven applications were further discussed. Firstly, we organized a discussion event to present and discuss the outcomes of the GSS session with participants and other representatives of the industry. Secondly, we did five in-depth interviews with participants of the session representing the chemical industry, the food industry and the suppliers. Based on that we further fine-tuned the applications; a summary of this can be found in the first column of Table 1.

4 ANALYSIS

The analysis of this case study focuses on the first trade-off as mentioned in section 2.4: 'how can we get the enabling technology to support an application that fulfils the demand of the users', i.e. the process industry.

The research aim was to gain an insight into the industrial view with respect to the current wishes and more future-oriented expectations regarding wireless applications in the process industry. Next, the industrial needs in relation to wireless application, as formulated by industrial experts during the GSS session and interviews, were commented on by the experts of the UWB technology. These experts are radio technology researchers in wireless networks from Delft University of Technology and Utellus, a R&D company[1]. In Table 1 the applications are marked in the 'Fit' column: the very promising applications are marked by "++', the neutral applications with "0", and the not appropriate applications with "—". Applications marked with "?' still need additional research to specify matching.

Possible Application	Market demand (From literature, GSS sessions and interviews)	Effectiveness of UWB (UWB expert opinion)	Wireless alterna-tives	What are the pros/cons of UWB w.r.t. these alternatives? (UWB expert opinion)	Fit
A1. Automatic registration and localization of persons A2. Automatic registration and localization of assets (machine parts, equipment, moving objects)	The registration and localization of persons with UWB is related to minimizing the risk in dangerous situations. Therefore the need seems to be more latent. Also because the interviewees see substitutes. The demand for the registrations and localization of assets is more often mentioned.	The high fractional bandwidth of UWB results in a high resolution and good penetration in materials. Initial tests in an urban area have demonstrated foot-type resolutions over a 4 km^2 area. Indoor resolutions (after propagation through many walls) of less than a foot have been reported as well. The ad-hoc nature of UWB also allows for a distributed knowledge of the location of the different persons.	Radio Frequency Identification (RFID), Wireless-Fidelity (WiFi), Global Positioning System (GPS)	UWB has a high resolution and good penetration in materials, in contrast to other techniques. Due to the simplicity of an UWB transmitter, UWB also allows for low-cost tags. The reader could be rather expensive though. Existing RFID technology also consists of low-cost tags and a high-cost reader, but it has a rather limited range (a few meters). WiFi has a good range but is less accurate than UWB. The WiFi transceivers are also rather bulky and power hungry. GPS, finally, does not have a good indoor performance and is rather expensive.	+
B. Tracking and tracing of products - (inline) quality control	UWB might offer added value when acting as active tags connected to basic sensors measuring	UWB is an intrinsic solution, for the same reasons as indicated in application A.	RFID	RFID might also be a good solution here, since we can place detectors on the route where the products pass, and the distances can be kept small. However, if the tags	0

[1] See www.ewi.tudelft.nl and www.utellus.nl.

	product's conditions.			need to transmit quality information, we require some type of active RFID, and UWB might be a possible solution for that.	
C. Rapid commissioning of process control equipment – in particular in pilot plants.	When it should be able to localize process control equipment – significant efficiency improvements are expected in commissioning.	The good localization properties, the large spatial capacity, the low tag cost, and the ad-hoc character, make UWB a possible candidate for this type of application.	WiFi	The radar-like localization capability of UWB makes it possible to detect where the sensors are located. WiFi also has this ability, but the accuracy is smaller. The UWB tags are cheaper than the WiFi tags. The ad-hoc nature of UWB, allows seamlessly removing or adding sensors to the network.	++
D. Remote control. Plant wide communications not related to process control. Secondary sensor & control networks like gauging in tanks, safety controls, piping, fire security and so on.	First impression is that there is an explicit need for better solutions. Some companies believe that ad-hoc networking will be the panacea in realizing super reliable and "self healing" connections.	The range of UWB is rather limited (a few tens of m). However, many transceivers will generally be deployed in the plant, which means that we can hop the data from one terminal to the next. Additionally, we can create many routes from the source to the destination, thereby introducing robustness in the system. The ad-hoc feature of UWB will help us to develop such ad-hoc networks.	WiFi , Bluetooth, Conventional radio systems.	It is known that the Universal mobile Telephone System (UMTS) and WiFi have a larger range than UWB. However, their data rate is a bit lower, and the related sensors would be more expensive. Bluetooth has a similar range than UWB. Relaying/hopping could be used to bridge larger distances, since it is expected that many wireless terminals will be spread out over the plant. Moreover, route diversity in such an ad-hoc network creates robustness against defect terminals or unforeseen obstacles.	++
E. Point-to-point communications over long distances	Measurement information has to be send over long distances. The areas might be scattered.	UWB might not be the best solution for this application, since its range is rather limited.	Public network, fixed lines, satellite.	Conventional communication systems with a large range, e.g., UMTS, are better suited for this application.	-
F. Mobile tool for operators to monitor and have remote-access to central control room (CCR) systems	Efficiency and safety will increase by handheld monitoring and control and remote access to CCR systems	UWB can accommodate very high data rates (a few hundreds of Mbps). Hence, the use of UWB could pay off for this application. Also, UWB is very robust against multipath fading.	Conventional radio systems, WiFi.	UWB can offer the highest data rates, but as discussed in application D, its range is rather limited. Hence, an ad-hoc network deployment is required to set up a connection over larger distances. UWB can also offer accurate localization. Due to the high bandwidth, UWB can also benefit from the large multipath diversity of the channel.	+
G. Measurement and steering of	Trend is for more sensor & control in rotating equipment –	Temporal behaviour of the UWB propagation channel for this type of	No.		?

rotating equipment	stressing current solutions.	application is not clear. Requires further investigation.			
H. Measurement data from unsafe zones to safe zones	No existing wireless system is really compliant to the strict regulations [like ATmosphère EXplosive (ATEX)] so there is still an explicit need to find or develop wireless systems that will be compliant.	The pulse-based UWB system suffers from a high peak energy, which could lead to safety problems. This depends on the safety regulations. This has to be further studied.	No.	Currently, only wired solutions are used for this type of application. The advantage of UWB for this application would be the low sensor cost and the large robustness against multipath fading. However, the high peak energy of pulse-based UWB systems could make this system more unsafe than existing wired technologies.	-

Table 1. Match demand and technology

To summarize, two applications look most promising (C and D), two applications look promising (A and F), one needs further research to be able to draw any conclusion since some expert opinions are very enthusiastic but the UWB fit is not clear at all (G), one is neutral (B) and two do not seem interesting at the moment (E and H). An important remark is that UWB is only interesting for wireless applications A, B, D and F if the network is covering the whole area.

Based on the results of the GSS session, interviews with industrial companies and the literature study it can be concluded that the promising applications, although not yet clearly lined-up, are sufficiently obvious to urge the process industry and the developers of UWB application to continue research and start demonstration projects. One of the industrial participants of the GSS session started a UWB testbed on one of its chemical plants to further research this. The expectation is that a hybrid form of technologies will be most rewarding.

5 CONCLUSIONS

This research shows how to include the wants and the needs of the customers early on in a technology-driven project. The group-based process introduced in this paper allows for an effective and efficient user requirements elicitation process. The inclusion of the customers early on in the process ensured that the developers and researchers of the UWB applications were very aware of the context which enables them to develop better services. Based on the output of the GSS process, application developers could add their knowledge, expertise and creativity to oversee the potential value of UWB technology for the process industry. Promising application areas proved to be seamless localizing process control equipment (to detect sensors etc) with sufficient accuracy; and remote control by making use of ad-hoc networking.

In this research we explored the potential of a new technology with managers from industry rather than the actual users. In the next phase we will build a testbed and ask users to play with the applications in a pilot situation. We advocate that this is only the first step (analysis phase) to gain insights in the industry's wants and needs.

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Appendix: Detailled outcome of GSS session

Seven most important opportunities that were worked out into solutions by the GSS participants are:

1. automatic registration and localization of persons
2. installing temporary measurements: pilot plant
3. communicating of sensors with control systems including on locations with long distances
4. tracking and tracing including quality control (inline)
5. mobile tool for operators to monitor and have remote-access to central databases
6. measurement and steering of rotating equipment
7. measurement data from unsafe zones to safe zones

Moreover, it turned out that it is not unambiguous to derive criteria that are important for the process industry managers when designing wireless applications. The following non functional requirements were mentioned.

Safety	safety of personnel; physical safety; safety for sparks; prevention of accidents; information safety
Reliability	not disturbance sensitive; no long communication time outs
Usability	fool proof; easier to install
Accessibility	distributed monitoring and control; guarding on distance; unmanned warehouses; permanent communication with employees; not too accessible see security; unlimited bandwidth; communication with equipment/people in closed rooms
Flexibility	speed in setting up control environments; flexibility for persons, flexible workspaces; more flexibility due to possibility of temporarily installations; speedy replacements
Affordability	cost saving - saving costs of wiring!; space saving; time saving; saving costs by avoiding legal obligation to have two persons in certain situations; “saving on human resource costs has more impact than saving on costs of wiring”
Durability	energy usage saving
Security	less sensitive for sabotage; take care that it is not accessible for third parties;
Availability	information on demand available; higher availability of communication media; online consulting of manuals
Exactness, accuracy	0.001% achievable?
Reusability	of sensors in consumer products
Compatibility	chemical compatibility
Maintainability	higher because availability of plant information
Testability	more possibility to experiment with measuring
Other ‘ilities’ that might be important but that were not explicitly mentioned are Portability, Scalability, Configurability, Adaptability, Interoperability, Traceability, Clarity and Replaceability.	

Table A. Non functional requirements

Based on the roughly designed solutions, the project members further described the context and application notions. As an example, a description of a possible application for one of the solutions can be found hereunder.

Installation of temporary measurements and control systems in a pilot plant

Context

As the process industry is confronted with more rigorous competition and increasingly short-term dynamics in supply and demand pattern, it is urged towards competitiveness and productivity enhancing strategies. Agility, a strategy maintaining a flexible production system, e.g. batch-wise mode of operation, is a formidable weapon to increase a company’s competitiveness and to secure business. However, batch processes are particularly difficult to manage due to frequent product changes, variability in product recipes, batch sequencing problems, the need for intermittent equipment cleaning, the dynamic character of each batch processing step. Wireless networks are a very promising candidate for communication purposes in a pilot plant or in a flexible batch-wise plant: after adaptation of changes in a production process temporary-measurement systems could be reconfigured and reused. Moreover, the plant of the future "the pipe-less plant" without any jumble of pipes and connections, where several processes can take place in the same equipment, calls for wireless networks which can easily be reconfigured. However, the present problems in the process operation could often be solved with temporary "plug and play" sensors.

Application notion

The flexibility of the application can be seen here as a design objective. During the developing phase an open configuration should be realized, so that the contact with already present sensors is easy to realize and a re-configuration should be simple. It should be stressed, that a clear-cut documentation is a conditio sine qua non for this.