TagItSmart

Smart tags driven service platform for enabling ecosystems of connected objects

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Qualytics

D2.1 Validation report

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Executive Summary

This document reports about the validation of the Qualytics approach, which is described in the deliverable D1.1 and specified in the deliverable D2.1.

The deliverable reports on two types of the analysis:

1) Validation of the developed system and
2) Presentation of the business concept.

The first part is related to the validation of the technical/software development of the Qualytics system. Qualytics extends our data analytics approach for the quality control in the home appliances domain. The focus is on the refrigerators, although the approach can be applied on an arbitrary scenario from this domain.

The domain is quality control and the assumption is that there is already data collected in some kind of tests before shipping products to be sold (usually called functional tests). In these tests different parameters are measured in order to check the variations which might lead to anomalies. The task was to connect this data with the data from the maintenance domain (or even users, at home), which is a completely new approach.

We used Thinfilm tags in order to get the measurements from the devices (maintenance service). Therefore, for the testing phase we have developed a new service which is specialized for the tag data, i.e. the data we obtain from the Thinfilm. We modified the initial scenario (QR based) slightly so that the Thinfilm technology can be used. The main modification is related to the ranges of the temperature that will be considered in the use case. Thinfilm delivered us the tags, which are operating in the range 15-30 grades. It monitors the temperature and flags if the temperature has changed from that range.

We received several tags for the experimentation. Since the tags are for the demo purposes, they can be used many times, which enabled us to do the various types of validations.

Regarding the business validation we provide our initial business approach in the form of the business canvas. We argue that the system is very novel and have a huge exploitation potential. We illustrate that the service as a whole is interesting for different cases which have similar settings.

We provided also indication about the innovation capacity of this work.

It is important to mention that, from the business point of view, the proposal contributes to the novel concept of the Digital Twin for the maintenance of home appliances. The approach focuses on the creation of Digital twins through a novel concept of *DigitalTwinization* of "non-smart devices[1]", which can be seen as an approach for their retrofitting[2], esp. from the point of view of enabling sensing of the values of various parameters. Indeed, by having this new sensing, done through smart tagging, additional data related to the monitoring of the system

[1] Devices which are not equipped with sensors for continuous monitoring of their vital parameters
[2] https://en.wikipedia.org/wiki/Retrofitting

behaviour is collected. This process can also support the real-time classification of the system behaviour (anomalous, usual), based on the model learned in the data analytics.

1. Introduction

1.1 Scope of the deliverable

This deliverable is part of the WP2 (Preparation and Validation), which main objectives are to:

- prepare and deploy system in the simulated use case context

- validate the proposed system, regarding technical and business criteria.

In particular the work is related to the validation process (T2.2).

1.2 Contributions to other WPs and deliverables

This deliverable is based on the work done in WP1.

1.3 Structure of the deliverable

The deliverable is structured in the following way:

In the second section, we explain the set up for the validation process and explain the validation context and concept.

In the third section we present the validation infrastructure.

In the fourth section we provide the details about the validation process.

In the fifth section we provide the analysis of the business concept.

In the sixth section we explain the innovation capacity

In the seventh section we provide concluding remarks.

2. Validation Set up

In this section we provide the details about the set up for the validation.

We start with the explanation of the validation context in order to explain the validation approach in this complex case.

In order to understand the application context for the validation, we introduced the concept of Digital Twins. It serves as the validation concept.

Thereafter we describe the structure of the process used in the validation (so called validation process).

In the third part we explain some of the techniques used in the practical implementation (esp. measurement).

2.1 Validation context

The work is based on our experience with the quality control in the assembly process of big home appliance vendors. There are two main open issues:

1. The quality control in the assembly is based on the thresholds set by experts
2. The quality control doesn't take into account the information from the maintenance process

The first problem can be resolved using data analytics and we already developed a service that learns values for quality control from the past quality control data (usually available as the data from so called functional tests).

The second issue requires a feedback from the maintenance process in order to understand the behaviour of the devices in the real operation. This is the part where TagItSmart technologies can be applied. We see two important usages:

A) For enabling data acquisition (measurements) by using smart tagging technologies

B) For supporting the integration of the measured data in the existing data analysis pipeline

Regarding A) we developed two strategies for the measurement:

1) Measuring (detecting) complex situations of interest (related to quality)

2) Simple thresholds checking (related to parameters which influence quality)

Regarding B) there are two types of integration:

1) Batch: collecting the measurement data in order to find patterns of behaviour in the larger datasets

2) Real-time: reacting on the current measurement data in order to avoid some problems that might arise in near future

We developed conceptual models for all above mentioned situations (A1/2, B1/2), which are inspired by the proposal text, as illustrated in the following figure

The validation phase is focused on the characteristics of the end-to-end quality control approach, i.e. how properly the “maintenance as a service at home” can be implemented.

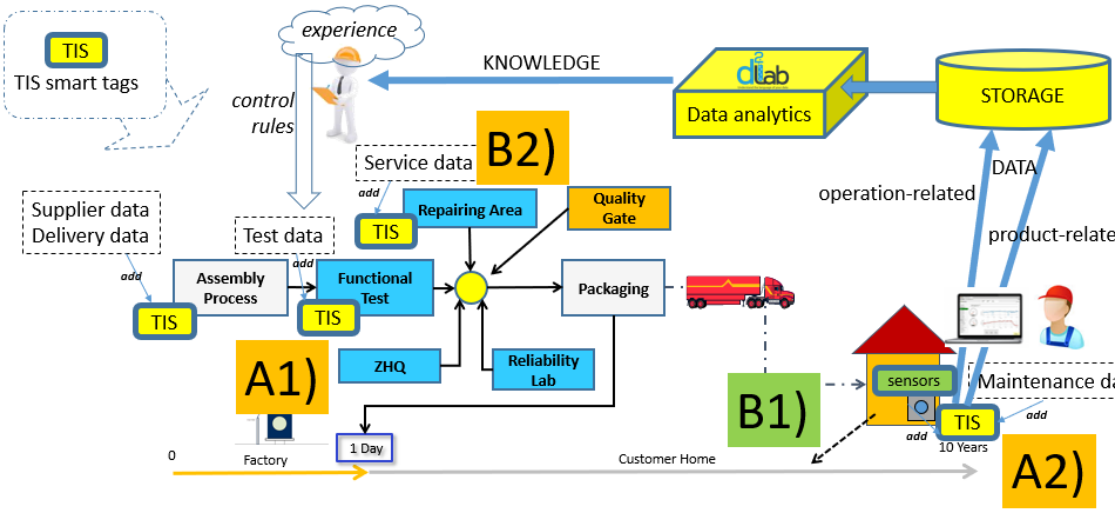

Figure 1: Mapping between the architecture and the selected processing modes (A1/2, B1/2)

2.2 Validation concept

Since Qualytics should be seen as the technology that contributes to the development of the business (e.g. the maintenance of home appliances), in this subsection we provide the explanation of our concept for the validation that connects the technology and the business goals.

In our existing work we have defined the concept of data-driven Digital Twins, as virtual replicas that are generated out of available data. Although very applicable in manufacturing in general, there is still a gap in the development of twins for the maintenance of home appliances

The main problem is the availability of the data for understanding the behaviour of a device since it (usually) requires sensing of some parameters of the device. We have developed a new approach that is based on replacing expensive sensing on the device level with the data analytics on the edge. The approach consists of several steps (Learning the model from past data, Developing smart tag that can represent the knowledge from the model, Reading periodically the tag and check the validity, Resolving gaps, Feeding the information back to the assembly process).

In such a complex process, the validation should be carefully designed. Indeed, the validation should show:

- Functionality and
- Reliability of the process

Functionality and Reliability are mostly depending on the quality of the MODEL, which is one of the most important elements of a Digital Twin. In other words, the Model describes the physical system, which the Digital Twin is representing

Main characteristics of the model are:

1. The creation process, i.e. how (easily) the model can be created (and maintained)
2. The quality of the model, i.e. how properly the model is describing the physical system

Model creation

The model is usually created by applying some theory/physics (numerical model). This can be a quite expensive process. Such a model is difficult for the management, since it requires a frequent involvement of experts

In a data-driven modelling process the model is created/learned using data analytics. The complexity of the process depends on the methods used for learning. The model can be maintained automatically, by assuming that the data analytics process is performed periodically.

Quality of the model

The quality of the model depends on the quality of a) the expert knowledge and b) the data available for learning and the selected learning algorithm. We are interested in the second case, whereas the learning is usually part of the server-side processing (determining the quality of the learning process).

Regarding our case of using Digital twins for the maintenance of the home appliances (so called edge-based twin), an important challenge on the edge is the possibility to represent properly the model (learned on server) on the edge.

There are two important questions in this context:

a) how precisely the model can be represent on the edge,

b) how dynamically it can be changed.

2.3 Validation process

In this subsection we show how the validation concept presented in the previous subsection can be implemented. We first start with the available technology (smart tagging).

The domain is quality control and the assumption is that there is already data collected in some kind of tests before shipping products to be sold (usually called functional tests). In these tests different parameters are measured in order to check the variations which might lead to anomalies. As we already described in deliverables, the task was to connect this data with the data from the maintenance domain (or even users, at home), which is a completely new approach. We used Thinfilm tags in order to get the measurements from the devices (maintenance service). Therefore, for the testing phase we have developed a new service which is specialized for the tag data, i.e. the data we obtain from the Thinfilm

This sensor belongs to the class of sensors which can be used for classifying values of some parameters based on the several (two) thresholds and some time-dependencies (durations).

This is a novel approach for the quality check and there are several parameters that can be tuned in this process. These parameters are the elements to be checked in the validation, like the length (time window) of the test sequence used for learning of normal behaviour and the window for collecting real-time sequences

The main advantage is that the sensor is less expensive and can be used in different scenarios. The main challenge is that the continuous signal of a parameter should be “approximated” with the discrete values (thresholds). In principle, we interpret the tag as the source of three values (-1, 0, 1), whereas “0” means that temperature is within the thresholds, “-1” means that the temperature is below the threshold for a certain period of time and “+1” means that it is above the threshold. This can be used for any type of parameters.

Figure 2 illustrates the coding process on a real dataset from the selected use case.

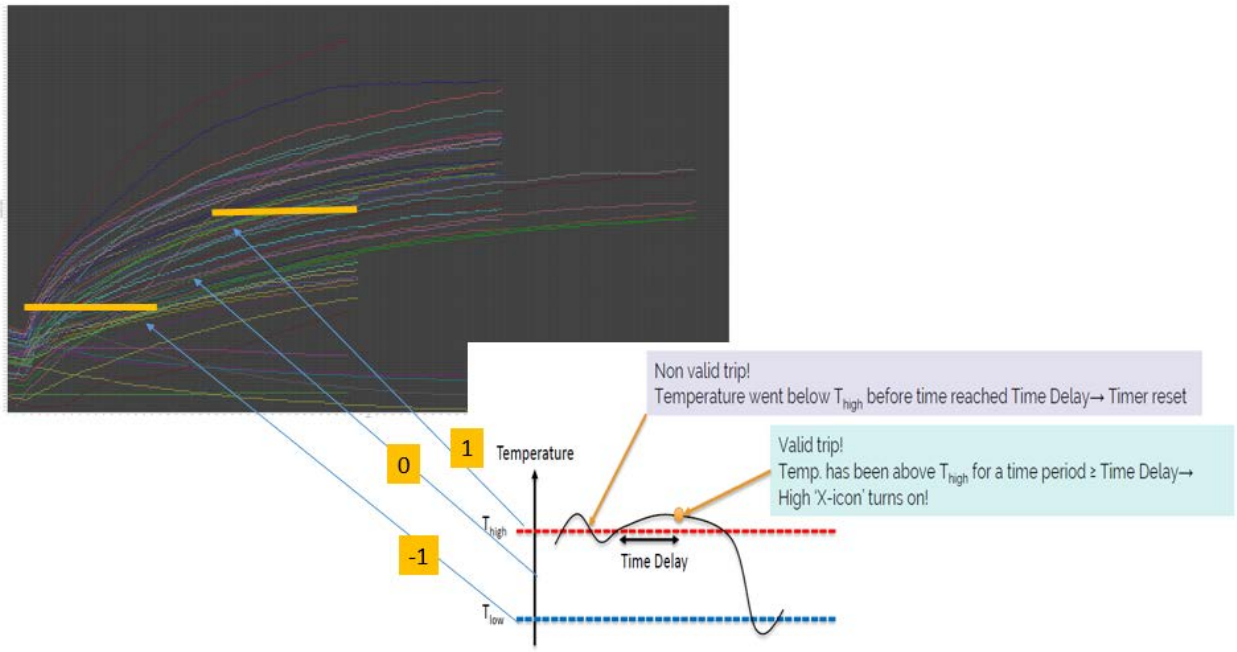

Figure 2: The mapping between the parameter data values and the sensor levels

The goal was to consider how the fridge motor is behaving after being switched on, i.e. are there any variations which can indicate any anomaly in that process. This is the process where the role of the above mentioned model is crucial and it should be validated properly

However, there were two main challenges in the process of applying the models:

C1: Technological: Thinfilm has hard-coded thresholds (temperature range) and delivers (-1,

C2: Domain: normal behaviour of the device in a (predefined) temperature range cannot be defined by experts

Especially important is C2 since it requires a very detailed understanding of the impact of a parameter (like temperature) on the behaviour of a device (fridge).

It is important to mention that the proposed approach is a novel one and enables mapping from high-granular models/measurement

In order to resolve these challenges, we used the following procedure:

1. Defining the normal behaviour of the fridges in the predefined temperature range

a) We used the available datasets for learning the normal behaviour of the temperature. This is data analytics task, based on D2Lab algorithms

b) We developed the method for selecting variations in the selected temperature range

c) We represented these variations as sequences of (-1, 0, 1) as described above. In that way we ensure that the output of analytics (normal behaviour) is in a form that can be obtained by Thinfilm sensors

2. Collecting the on-line measurement data (Thinfilm) from a real fridge

a) Setting the sensing process (Thinfilm)

b) Recording the changes in the tags

c) Coding the changes as the sequences of (-1, 0, 1)

3. Checking if the collected sequence belongs to anomalies

a) The learned normal behaviour is used for the test. This is real-time data analytics task

b) The system retrieves 0 (clustered as normal) or 1 (outlier)

3. Validation Infrastructure

In this section we describe the infrastructure we developed for enabling the validation process. It is important to emphasize that the proposed system is rather complex since it includes a part related to a production environment that delivers the production data and another part that is related to the customer context (home) that delivers the maintenance data. Consequently, there are two phases which are required for the validation of the proposed data-analytics based quality control systems:

- In the first phase the specific quality control model should be learned.
- In the second phase the model is applied on the real-time data in order to check their quality.

These two phases correspond to two characteristics of the model (concepts) mentioned in Section 2.2.

In Figure 3 we present the processing infrastructure used for the preparation of the tests.

Very briefly, the first processing step is related to enabling the transfer of relevant data that will be used for learning the models for the anomaly detection, It is important that this process is organized in an efficient way in order to ensure that new models will be generated regularly.

In the next processing step we perform the learning process that is adapted to the requirements from the use case. This process generates models that will be used in the detection process

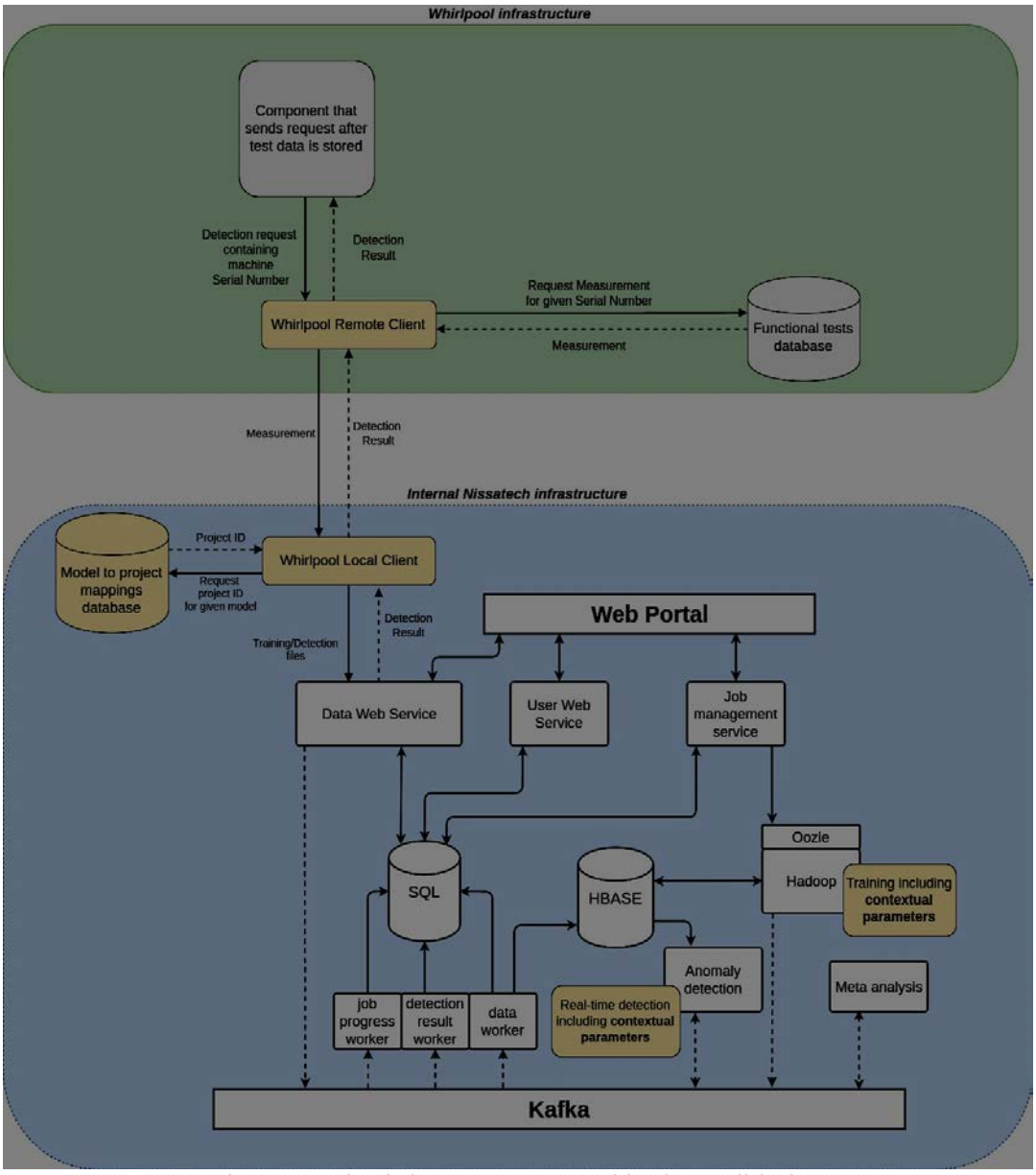

Figure 3: The infrastructure used in the Validation

In the following text we describe the most important components

1. Remote Client

This client is implemented as service with endpoint for requesting detection for machine with given serial number. When it receives detection request, *Remote Client* queries *Functional tests database* using serial number in order to retrieve measurement data. After data is retrieved, it adjusts data format before delegating the request to *Local Client*. After getting an answer from *Local Client,* it returns detection result to it's client.

2. Local Client

This client is also implemented as service with endpoint for detection request. As mentioned, it receives request from *Remote Client.* The request contains measurement data and model number(12NC column from Whirlpool database). This model number is looked up in *Model-to-project mappings database. Local Client* also contains endpoints for adding and removing mappings from this database.

3. Model to project mappings database

Contains pairs of modelID-projectID. It can be altered using *Local Client* endpoints.

4. Training procedure

Training procedure had to be extended to support analysis which includes contextual parameters (temperature). Specific steps were needed to determine the influence of contextual parameters and to emphasize it.

5. Real time anomaly detection

This is the most important part for the quality control

Influence of contextual parameters also had to be included in real time anomaly detection. Similar steps need to be performed during both phases, to have an identical workflow for a functional test, regardless of whether it comes for training, or in real time, for anomaly detection.

4. Validation

In section 2.3 we provided the structure of the validation process. In this section we provide details of the concrete process for quality control.

In the validation process of a quality control approach, there are two main challenges:

Challenge 1: Is the generated model correct?

Challenge 2: Is the detection of the anomalies precise and reliable?

These challenges correspond to validation concepts mentioned in Section 2.2 and in the following text, we provide details for the validation considering these two challenges.

4.1 Challenge 1: Model for the validation

One of the biggest challenges is to ensure the learning of the model that satisfies the constraint defined in section 2: considering only the valid part of the measured values. Following text describes the process.

4.1.1 Data set

The available data set from the functional tests is used for the validation. Due to confidentiality we cannot disclose all details, but provide the most relevant ones:

- There are 44165 functional tests for the selected model from the production
- Each tests contains about 200 values (time window)

We focus in the learning phase on the impact of the temperature.

The analytics task is done using the system described in D1.2.

4.1.2 Visualisation

We apply Dimension Reduction to visualize data set. The 85% of whole data set can be described with 3 components. 92% of *standardized* data set can be described with 3 components.

Figure 4 represents the 3D View on the dataset after dimension reduction

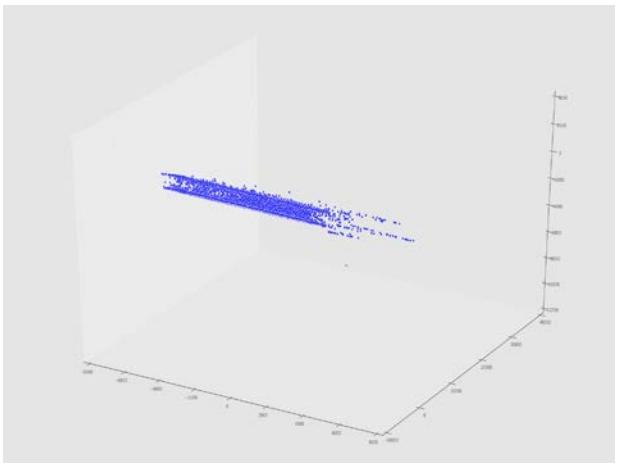

Figure 4: 3D View on the selected dataset

3D Standardized Data

The data is standardized in order to give all the parameters the same importance. It is one of the very well-known preprocessing techniques. Standardized data is presentes in the following figure.

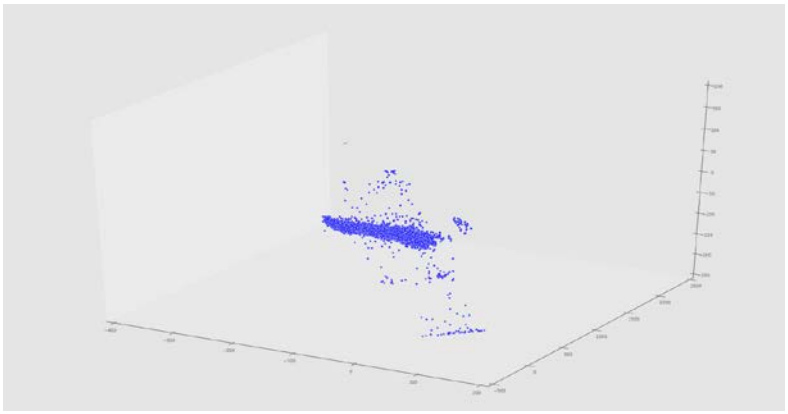

Figure 5: 3D View on the standardized data

We can notice that there is one big oval cluster and some instances and small groups around that big cluster. The task of the data analytics is to find the most appropriate model for the interpretation of the temperature (i.e. its role on the quality)

Temperature periods

We were suggested to switch to Thinfilm technology. However, this technology can support “only” the detection of threshold based situations, as presented in following figure

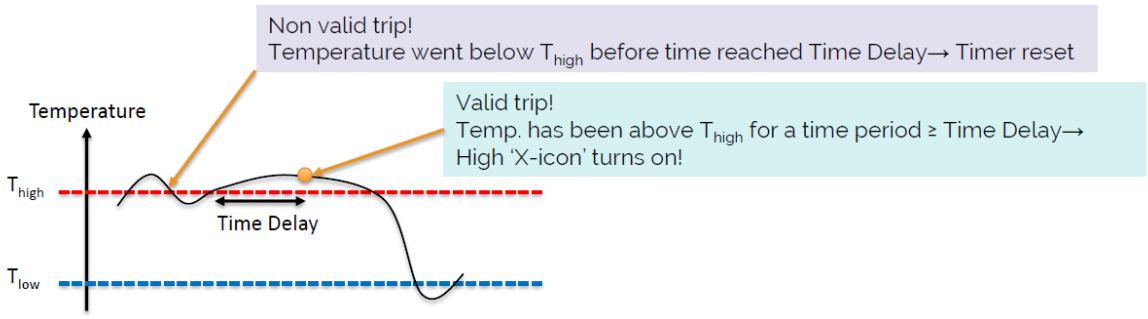

Figure 6: Thinfilm sensor illustration of processing changes in the temperature

4.1.2 Validating the right model

One of the most critical tasks in the developing the model through the clustering process is the determination of the right number of clusters. The quality of the clusters is usually inspected manually (except in the case of automatic clustering where the optimal number of clusters is determined using a special procedure).

The following figures illustrates the quality of clustering using different number of clusters (2-5). Different colours are used for depicting instances from different clusters

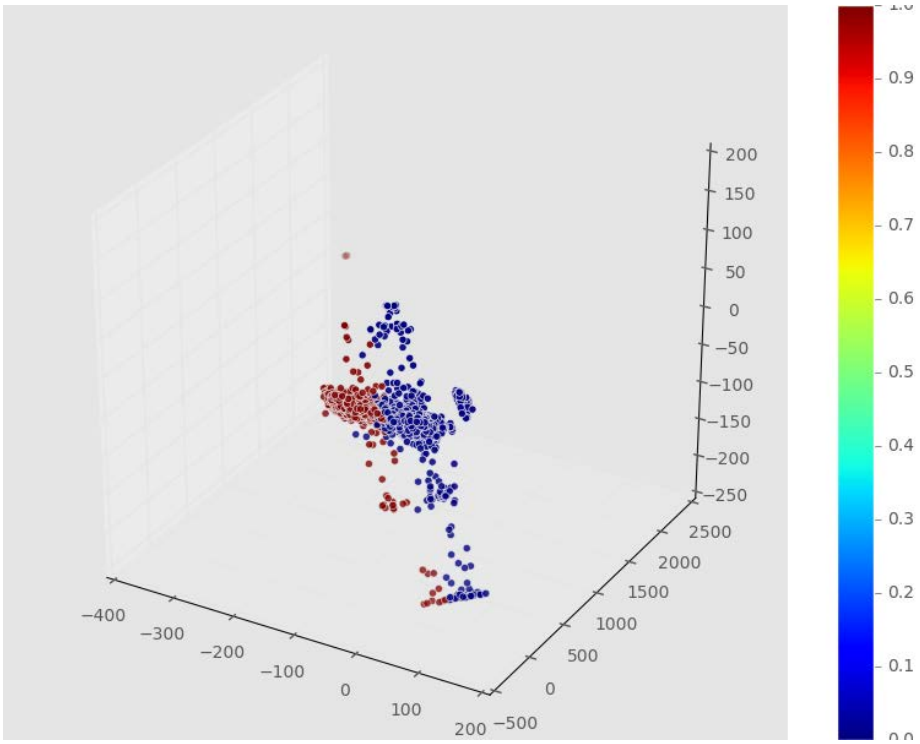

Figure 7: Clustering using 2 clusters

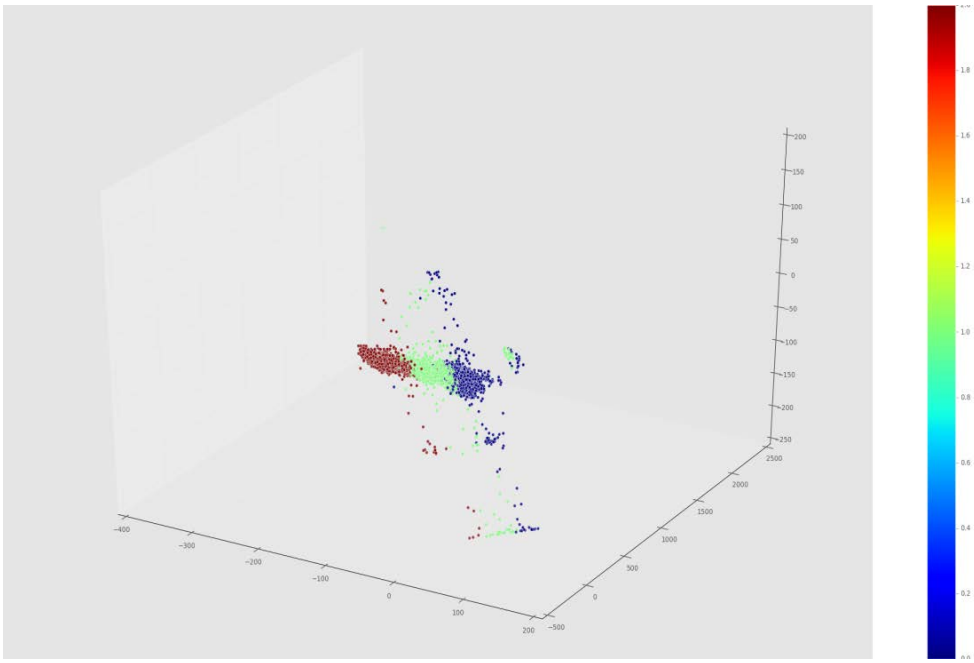

Figure 8: Clustering using 3 clusters

Ssssw1`

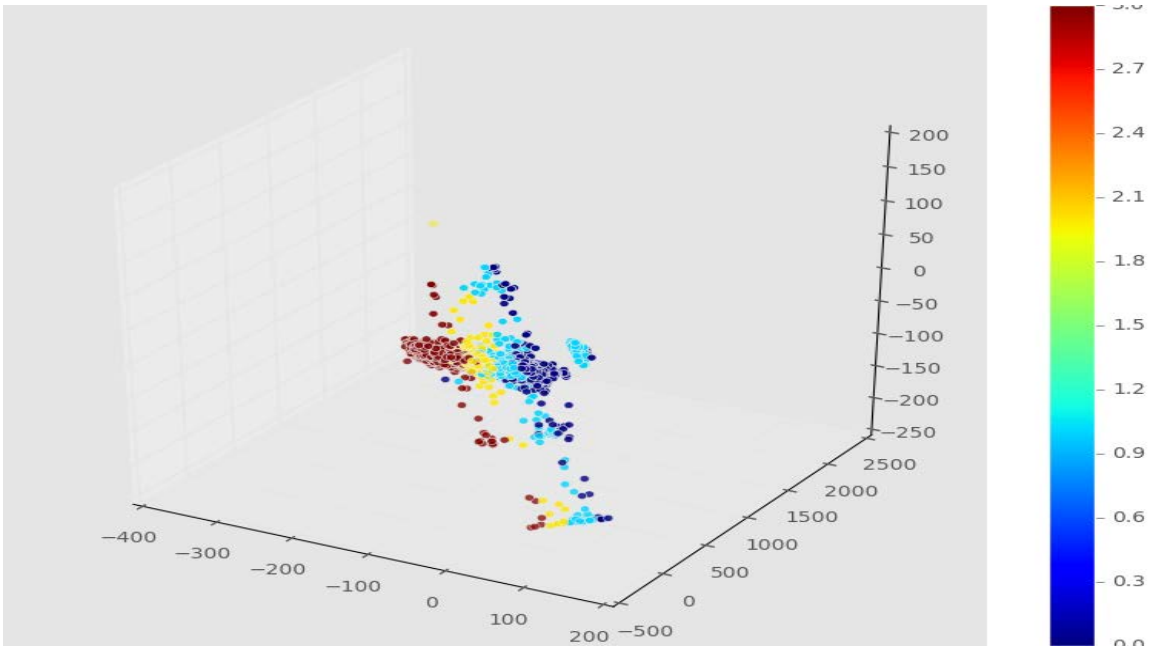

Figure 9: Clustering using 4 clusters

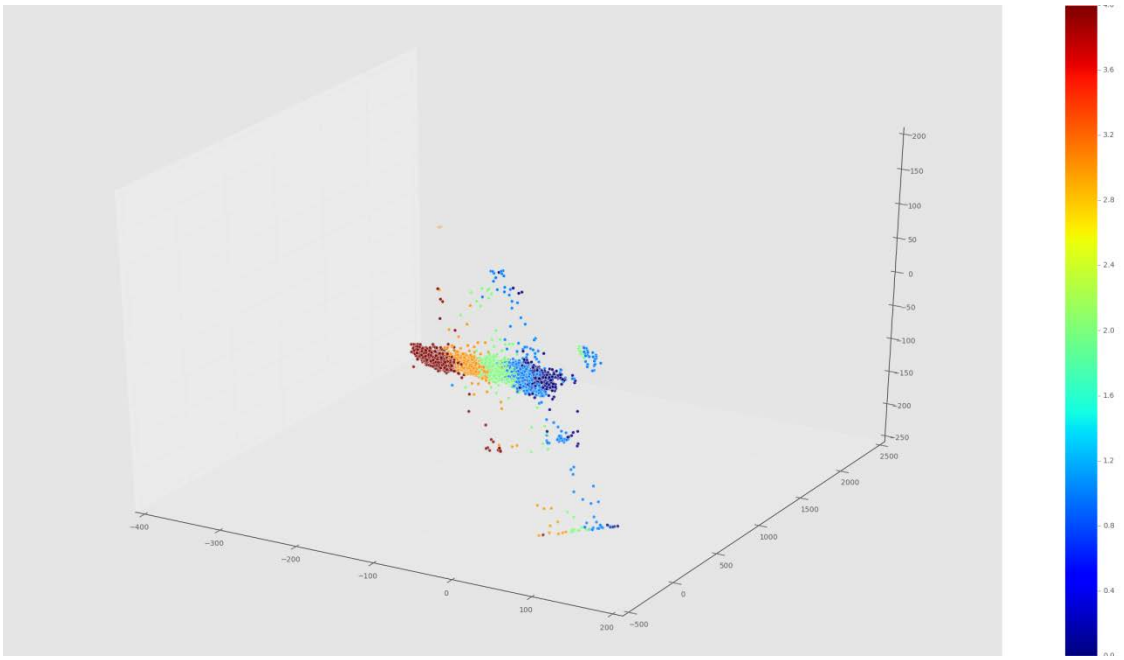

Figure 10: Clustering using 5 clusters

The conclusion is that a quite granular clustering is possible, which makes the detection process very precise (the model is detailed).

4.2 Challenge 2: Validation of the detection process

After the creation of the model, as described in Section 2, it is applied on the collected real-time data in the home maintenance context.

In Section 2 we also explained the challenges for the generation of the useful input signals from Thinfilm sensor and the process to doing this.

Only challenge for a sound validation is the number of the instances that can be generated in the test process, if performed only manually. This is important for the maintenance case since it cannot be assumed that many maintenance cases will be available

The goal is to check how the Thinfilm-based sensing is able to:

a) Provide useful/correct input signals

b) Provide correct classifications (based on the learned models)

Bevor providing the validation details, we explain also the technique for sensing

4.2.1 Measurement techniques

In this section we describe the principles how the required, quality-control related measurements can be realized using Thinfilm.

In Section 2.3 (Figure 2) we illustrated the process of mapping the sensing from Thinfilm into the data used in the learning process.

This is the most interesting usage of the TagItSmart technologies, elaborated and discussed with different project partners. It enables the representation of complex situations (usually defined as complex event patterns).

4.2 2 Correctness of the sensing

The task is to check how the discrete way of sensing (Thinfilm) can support the continuous signal based detection process, focusing on the quality of the generated „continuous“ signals

The test was performed using 120 selected signals, similar to presented ones.

The validation goal was to check how:

a) Stable

b) Fast

c) Reliable

d) Precise

is the Thinfilm-based measurement process.

These are the most important features for a measurement related to quality control:

- Stability is defined as the repetition of the measured values for the same input signals (calculates as the ratio between measured and expected)
- Fast is related to the average duration of the measurement process. Since the reading was done manually, this couldn't be validated properly
- Reliability is defined as the possibility to get correct measurements in the long run (calculates as the ratio between measured and expected)
- Precision is defined as the matching between sensed and expected values (calculates as the ratio between measured and expected)

In order to test the influence of the context, we define two contexts, standard (as planned) and with some small deviations.

In the following table we provide the summary of the validation.

Table 1: Correctness of the sensing

Cycle	Number of cases	Context	Stability	Reliability	Precision
1	90	standard	100%	100%	100%
2	30	non standard / borderline	100%	90%	90%

The only problem faced is related to the precision in the case of some "difficult", borderline cases (the temperature was changing too fast)

Conclusion:

Thinfilm-based measurement process is of the high quality for the planned approach.

4.2 3 Precision of the anomaly detection process

The main goal of the proposed approach is to enable an improvement in the maintenance process, which can be done by using local sensing/measurement and remote expert knowledge (generated from data).

Therefore, the task for the validation was to check how precisely the potential anomalies can be found. It is important to emphasize that the notion of “precision” in the quality control can be interpreted in different ways. For example, some approaches are “only” considering so called “out of limits” anomalies, which means that for a selected parameter only a lower and upper threshold are considered. We apply an advanced, data-driven approach that analyses the flow/trend of values and not only the relation to some predefined limits. We argue that this approach has many advantages. We argue also that the described Thinfilm based approach is very suitable for this type of the quality control.

However, since this kind of validation requires a bigger dataset containing also anomalies, it was difficult to instantiate the validation environment, presented in Section 3. It was decided to simulate some of the anomalies (in the production) according to the measurement process described above. This process is supported by the models derived using data analytics, i.e. these models indicate how the anomalies can be “defined”.

This model-driven approach has the advantage of contributing to the so called “process understanding”, i.e. understanding normal behaviour of the system. In other words, it is possible to discover not only that a process (production of fridges) is working properly, but also to understand how properly it is working, e.g. are there any different “modes” of the normal behaviour. From the quality control point of view this is also an important information: are there any “variation” in the process, which might be “allowed” but which indicate that the process is not in a stable state (that is a problem for the process improvement since only a process which is in a stable state can be improved).

Therefore, we performed two types of the testing:

1) Can the anomalies be detected?
2) Can the unusual behaviour be detected?

In order to validate these challenges, we set up the following test:

1. the set of measured signals from the first validation was taken

2. additional signals are generated including

- small variations from existing clusters, but not outliers
- the deviations from the learned clusters (outliers – anomalies)

3. the clustering process is started in order to validate if a new cluster will be defined

4. the anomaly detection process was performed in order to check its validity

Regarding the 3., the clustering process defined a new cluster of the usual behaviour (as expected, based on new dataset). This is an important conclusion confirming the quality of the Thinfilm-based measurement process

The following table summarizes the outcomes from 4.

Table 2: Precision of the anomaly detection

Cycle	Number of measurements	Anomaly detection: Precision	Anomaly detection: Recall
1	120	80%	100%

It is important to mention that the validation of the (data-driven) quality control systems is difficult since the criteria for detecting “valid” cases are not formally defined (but encoded in the data-driven models). Usually, the systems are designed to be more “flexible”, i.e. to prefer the “recall” to the “precision”, as depicted also in the table above.

Conclusion

The quality control system behaves as planned, by assuming that the model is generated properly and that the sensing/measurement process is done in a valid way (as validation has shown).

We argue that the main issue is the quality of the measurement process, which is based on the Thinfilm sensing

5. Business validation

5.1 Business case

In deliverable D1.1 we present a detailed description of the business use case: “Improving quality control by managing temperature fluctuation patterns based on smart tags”. In order to improve the readability of this deliverable, we repeat some explanations about the business case given in D1.1

The goal of the scenario is to define the procedure for checking the quality of the maintenance service performed on a part of a product/machine that depends on the temperature fluctuations. In this case it is the cooling part of a refrigerator.

The particular problem in the maintenance process is an unstable behaviour of the cooling part after reparation, which is reflected on the fluctuation of the temperature in the fridge, usually happening in the first days after reparation. However, our approach is based on connecting data, so that the data from maintenance process will be combined with the data from manufacturing (assembling) process.

Indeed, the fluctuations are also observed in the functional tests performed after assembling process, so that the knowledge about the shape and duration of some fluctuation are known. Since there are different types of the fluctuation, we will focus on those which range corresponds to the characteristics of the smarttags (Thinfilm).

As Is – current problem

The existing procedure does not enable remote checking of the fluctuations in the temperature.

The main motivation is coming from the problems with the quality of delivered devices:

a) testing in the factory is incomplete but costly and

b) customers are sometimes experiencing bad quality of delivered devices (although testing phase was positive).

To Be – Additional requirements

There are several new requirements comparing to D1.1:

- The solution should be easy to install / de-install and if possible to be reused;
- It should be installed by the non-experts;
- It should serve as the quality check for the maintenance process.

The system combines IoT and Data Analytics for Quality Control. The main goal is to integrate:

- Information about the behaviour of a model (data analytics from functional tests)
  - Requested for the definition of the range in the fluctuation of the temperature (data analytics);
- Measurements after service/repair based on the customer complaint
  - Checking the validity of the fluctuation in the temperature (tagging technology);
  - Customer is reporting the measurements outcome.

One of the most important functionalities in the quality control is the detection of the unusual/abnormal behaviour, which we consider as a “detector”.

Based on our analysis of industry cases we distinguish between the simple and complex detectors.

- **Simple detectors** are reacting on the rather smaller and shorter situations of interest. They are usually recording a situation, where there is a need for detecting that a specific situation has appeared at least once in the selected time period.

  One of the main constraint is that the reading of the status of the detector can be performed only manually (visually). This makes the entire detection process less automated (i.e. it is not possible to make the whole end to end process in an automated way). On the other hand, this process of simple detection aims to recognize the situations, which are classifying the operation of the system into acceptable and anomalous, whereas it is not needed to react in real time.

- **Complex detectors** are reacting on complex situations of interest, which are usually some combinations of simple situations (that can be based on simple detectors). They are usually used for determining if the system behaves as planned in the longer run (operation).

The following table compares the characteristics of the both types of the detectors:

Table 3: Comparison of the detection process

Characteristics Detector type	*Complexity of sensing*	*Need for reaction*	*Type of decision*	*Usage*
Simple	Basic	On query	Classification (proper, anomaly)	One shoot
Complex	Composed	On demand	Clustering (type)	Continuous monitoring

The main advantage of the approach is the possibility to check some hidden variations/fluctuations in the temperature, which can indicate some anomalies in the operation of a device. This has two positive implications:

1. Some important information related to the temperature fluctuations can be captured (using low cost technologies). For example, it is possible to define a very precise temperature range that should be observed;
2. The customer can be more actively involved in the maintenance process.

We argue that such an approach can change the way how the maintenance process can be organized in order to enable much faster discovery of problems.

This approach is the first step in developing a larger edge event collection system that is able to easily detect specific events that might influence the usual/proper operation of the system.

5.2 Business Canvas

Business Canvas is one of the most important methods for describing business-related concepts (model).

Following figure represents the Qualytics Business Canvas

<table>
<tr>
<td rowspan="2">-</td>
<td>Key activities
Platform development and operation
Development of analytics (methods)
Testing the methods, PoC
Finding early adopters in industry
Marketing and community building</td>
<td rowspan="2">Value propositions
Better exploiting the value of the past data produced in the production/business process for the quality control
Connecting the data silos: production and maintenance
The possibility to check some hidden variations/fluctuations in some parameters (e.g. the temperature), which can indicate some anomalies in the operation of a device
More actively involvement of customers/users in the maintenance process
Enabling new services related to the maintenance process
Better reaction on problems in the quality control (in near real-time)
Automate the inspection of the data generated in the maintenance service
More efficient quality control process, multidimensional quality control
Eliminating the bias defined by human experts in the quality control: automatic definition of thresholds</td>
<td>Customer relationships
Call center support
Co-creation (of services)
Customer community portal
Social network presence
User workshops
Strategic partnerships</td>
<td rowspan="2">Customer segments
Manufacturers of the products that
- need to be maintained in a more efficient way (e.g. costs are high for customers)
- are used in various ways by customers (general prescriptions are inaccurate)
Manufacturers who want to connect the data from the production and the maintenance process
Maintenance service provider companies which want to introduce better monitoring of the usage of the customer products (to enable a more efficient maintenance service)
Business with problems in quality control (esp. for functional testing)
IT suppliers of manufacturing companies who want to extend services with exploiting data about the usage of the product (or monitoring the usage)</td>
</tr>
<tr>
<td>Key resources
Technology and infrastructure
Quality control experts who understand the idea
Business process improvement managers who support the approach
Software services
Financial resources</td>
<td>Channels
Awareness: Social networks, Web page, Workshops, Press
Evaluation: Free trials in industry
Purchase: Portal
Delivery: Web services, apps, Community Portal
After Sale: Call Center, issue tracking system</td>
</tr>
<tr>
<td colspan="2">Cost structure
Development (human resources)
Consulting (quality control experts)
Technical Infrastructure, e.g. cloud
Pivoting costs
Industry community building costs
Marketing and Sales
Administrative
Software licences
Patents</td>
<td colspan="3">Revenue streams
SaaS (Software as a Service) subscriptions: monthly fees, different subscription models (basic, advanced, premium)
Additional services based on monitored data:
- data analytics (e.g. predictions based on the data from the production)
- recommendations for improving the maintenance process</td>
</tr>
</table>

Figure 11: Business Canvas

The most important part of the Business Canvas is related to the Value propositions, which we provide some comments for:

- Better exploiting the value of the past data produced in the production/business process for the quality control
    - This is related to the possibility for generating knowledge about usual (unusual) behaviour of the system

- Connecting the data silos: production and maintenance
    - This is related to the opportunity for integrating data from the manufacturing (production context) and the maintenance services (usage context)

- The possibility to check some hidden variations/fluctuations in some parameters (e.g. the temperature), which can indicate some anomalies in the operation of a device
    - This is related to the possibilities to detect some early warnings in the operation of a device

- More actively involvement of customers/users in the maintenance process
    - This is related to the new role of a customer in the maintenance process, i.e. increasing their engagement in the maintenance
    -
- Enabling new services related to the maintenance process
    - This is related to opening a new potential for developing business through the creation of new service based on collected data and analysed situations

- More efficient quality control process, multidimensional quality control
- Eliminating the bias defined by human experts in the quality
    - These two are related to the improvements in the quality control based on new real-time analysis

6. Innovations outlook

In this section we provide an analysis of the innovations created in the approach on different levels: business, technology and industry.

6.1 Business context:

Main effort in the conceptualization of the solution was related to understanding the potential of the tagging technology for providing novelties (added value) to the home appliance service (maintenance process)

We analysed the problems in the current maintenance process and have concluded that this proposal can resolve the following ones:

a) using the knowledge from the production (assembling) process in the maintenance service in a more dynamic way. Usually the maintenance personal is getting the guidelines from the production/assembling in the form of some thresholds. However, these thresholds can be changed (based on different changes in the production, incl. the usage of some new suppliers) This is quite suitable for the smart tagging technology which can be adapted on demand. In other words, the maintenance personal is getting a very useful mechanism for updating the knowledge about the maintenance service

b) collecting data about the usage of the devices in the context of:

- a particular customer (how does she/he use the device). This is important for understanding the preferences of a customer and offering to her/him personalized service

- a type of the device, by assuming that customer will use the devices in a similar way, or that devices will behave similarly in a period

c) performing maintenance with a less expensive (novice) personal by retaining the high level of the quality of services. In the general case, the maintenance is done by the professionals who have a considerable experience. Indeed, the quality of the maintenance depends on the experience of the maintenance personal. The main reason is that the knowledge about the maintenance is part of the individual experience, i.e. a person becomes an expert if she/he analyse many cases.

d) involving customers in the maintenance process (as much as they want). Usually, the customer would be ready to support a part of the maintenance in the case that some benefits (better, less expensive process).

6.2 Technology context

Since smart tagging is a novel technology it opens many opportunities for technology innovations in the selected domains by extending the existing service flow. The main advantage is the “small” size of the sensors, lower price and possibility to work with different sensors.

There are two innovations related to the maintenance service for home appliances which are driven by the smart tagging technology:

a) describing the models of the usual behaviour which are suitable for the deployment on the devices (home appliance) using the thermo-sensitive tagging.

b) controlling some of the critical parameters for the proper functioning of a device (home) in the format of some patterns (of interest)

We assume that the devices are not smart one, i.e. already equipped with different types of sensors (smart devices). This is usually the case for most of the households: smart devices are still expensive and not affordable

6.3 Industry context

We argue that the proposal has progressed beyond the planned scope, which should be seen as a positive development, mainly due to two reasons:

- very constructive/creative discussions with the potential users, who expressed various opinions about the technology (from the use case point of view) ans
- progress in our internal development of the concept Digital Twins, whereas the usage of Twins in the maintenance has become very interesting

There are three main contributions to the innovation in the quality control / maintenance in general

1) Digital Twin for the maintenance of home appliances

The most important elements are:

- the concept/architecture
- the model (learning process) and
- the detection process (matching the model and the real data).

For all three we provide a specific approach based on the given technology (smart tags) and the use case (quality control).

2) Edge processing (edge twins)

Enabling the processing of the sensor data as close as possible to the edge (shop floor) in order to enable a more efficient reaction in the case of emerging problems.

3) Supporting Retrofitting

Although Industry 4.0 is introducing the automatization / digitalization everywhere, in many companies the need for a step by step progress and improvement/upgrade of the existing machines is welcomed. We argue that for a certain type of applications (like maintenance), a rather light-weight approach with smart tags can be very practical. It is clear that such an approach should be designed properly in order to exploit the potential. Although the approach seems to be “simple” for the implementation, it requires a considerable effort in the design

Our approach can be classified as this one, with the focus on home appliance domain. The main challenge is the design of the patterns which are required for the monitoring on the edge. Usually, the complex models which are learned should be rewritten in the forma that can be supported by the smart tag technology

7. Conclusion

This document reports about the validation of the Qualytics approach, from the technical (mainly) point of view.

The validation has shown that:

- Thinfilm-based measurement process is of the high quality for the planned approach.
- The quality control system behaves as planned, by assuming that the model is generated properly and that the sensing/measurement process is done in a valid way (as validation has shown).

We conclude also that the main issue is the quality of the measurement process, which is based on the Thinfilm sensing.

The business case is related to “Improving quality control by managing temperature fluctuation patterns based on smart tags”. We provided initial business canvas in order to illustrate business model.

We provided also indication about the innovation capacity of this work.

Exploitation process is in progress