TagItSmart!
SmartTags driven service platform for enabling ecosystems of connected objects

Grant agreement 688061

Deliverable ID: D 2.1
Deliverable Title: Semantic model for FunCodes
Revision #: 1.0
Dissemination Level: Public
Responsible beneficiary: VTT
Contributing beneficiaries: UNIS, DNET, UPC, TFE, SIE, VTT
Actual submission date: 27.1.2017

Start Date of the Project: 1 January 2016
Duration: 36 Months
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Section 1 - Introduction

TagItSmart project sets out to redefine the way we think of everyday mass-market objects not normally considered as part of an IoT ecosystem. These new smarter objects will dynamically change their status in response to a variety of factors and be seamlessly tracked during their lifecycle. This will change the way users-to-things interactions are viewed.

Combining the power of functional inks with the pervasiveness of digital (e.g. QR-codes) and electronic (e.g. NFC tags) markers, millions of objects will embed cheap sensing capabilities thus being able to capture new contextual information. Beside this, the ubiquitous presence of smartphones with their cameras and NFC readers will create the perfect bridge between everyday users and their objects. This will create a completely new flow of crowdsourced information, which extracted from the objects and enriched with user data, can be exploited by new services.

TagItSmart will create an open, interoperable cloud-based platform with all the tools and enabling technologies, which will address the challenges related to the lifecycle management of new innovative services capitalizing on objects “sensorization”. TagItSmart will empower all steps involved from creating smart markers, Functional Codes (FunCodes/FCs) / SmartTags, to supporting secure and reliable acquisition and consumption of such contextual data, while preserving user privacy, to the provision of generic functionalities and a service composition platform, which will allow even inexperienced users to create and deploy their FCs based services while maintaining system efficiency.

The goal of Work Package 2 (WP2) of TagItSmart project is to create the enabling technologies that allow generating and managing functional codes. One WP activity is to create a model for identifying the tags to be used, according to their possibilities and limitations, and to the required sensing capabilities the functional codes should provide. This model is defined as a semantic model able to capture the information related to all the aspects involved in the functional codes life cycle. Semantic model is designed in task T2.1 (Semantic Model for FunCodes) and this deliverable D2.1 reports the details of the created model, and the other relevant related activities carried out in task T2.1.

This deliverable D2.1 of TagItSmart project reports the specification of the proposed semantic model to capture functional codes (FCs) and the associated information gathered as part of the scanning process. The semantic model presented takes into account capabilities and practical limitations of the functional inks and the printed NFCs. The model allows the possibility to easily combine data generated by FCs during their usage with the other existing data sources, obtainable from e.g. FC-scanners, thus guaranteeing semantic interoperability.

The rest of this deliverable is structured as follows. In Section 2 related work and state-of-the-art on semantic models is presented. Section 3 lists technologies and their properties required in semantic model definition. In Section 4, general semantic model requirements and those specific to the defined project use cases are presented. Section 5 presents the overview of the functional codes semantic model. Section 6 concludes the deliverable and discusses directions for future work.
Section 2 - State-of-the-art on Smart Object modelling

This section provides an overview of relevant state of the art on contextual codes and semantic data models and data standards for smart object and device modelling, drawn from EU project initiatives in the IoT area as well as the wider research community. Semantic models describing the associated topic of observation and measurement data are also reviewed here. This will help in building the model when relevant background information is used as a starting point to modify existing models for the purposes of FunCodes modelling.

2.1 Related Work on Contextual QR Codes

Efforts to automatically identify and attach information to individually tagged products include prototype applications developed at Xerox Parc in 1999 such as augmenting books and documents with RFID tags and linking them to associated services [1].

More recently, the prevalence of 1-D and 2-D codes for conveying enhanced information has been explored through proof-of-concept applications such as the mobile phone-based Allergy Assistant [2] that recognises a product information through its barcode and associates it with a person’s predefined profile (containing his/her known allergies) to provide on-screen cues as to whether the product is suitable for consumption. Other approaches feature orientation specific user interaction that shows different information and services dependent upon the rotation of the phone while scanning the barcode [3].

Figure 1. Contextual QR code
While the above approaches have used the statically encoded information in the codes, Rouillard et al. [4] have looked at including the context of the scan to present dynamic information. The developed application merges the decoded QR code information along with context information obtained from the scanning mobile phone, such as device, user’s profile, location, time etc., as shown in Figure 1. However, the information coded inside the QR code remains static, unlike the dynamic SmartTags being developed in the TagItSmart project.

### 2.2 Smart Object ontologies

Recent EU project initiatives have looked at applying semantics to model IoT-specific elements, including things and the functionalities they provide. With the IoT domain providing the possibility of everyday objects providing real world data to the Internet, the associated models should include metadata describing the objects to provide context to the descriptions.

The IoT-A project\(^1\), defined the IoT domain model [5], that specified the trio of entity, resource and service as the main elements of the IoT. Inter-relationships between these three concepts, as well as further specialisations, were also defined. A semantic model [6] for entities, resources and services was also proposed, with resources forming the software representation of device functionalities. The resource model specifies resource types (e.g. sensor/actuator/gateway node), the location of the corresponding device as well as a link to the service model that exposes the resource capabilities. The location can be defined in terms of the geographical coordinates, to an external ontology instance such as that in GeoNames\(^2\) or through a URI to a local location ontology, such as that which provides detailed location description of rooms and buildings in a campus [7]. A simplified version of the resource model proposed in [6] is shown in Figure 2.

![IoT-A Resource Model](image)

**Figure 2. IoT-A Resource Model [6]**


\(^2\) GeoNames ontology, [http://www.geonames.org/ontology/documentation.html](http://www.geonames.org/ontology/documentation.html)
A similar device model is proposed in [8] and in [9] with resources identified as the computational element of a device and categorised as on-device or network resource to represent events in an IoT environment.

A domain independent ontology from the oneM2M standards initiative is the oneM2M Base ontology [10], shown in Figure 3, that features a Thing as its root concept. A root class thing represents an entity in the oneM2M system, and its refinement, the Device class represents a thing which can interact electronically with the environment. A device has one or more functionalities (i.e. capabilities) which are exposed to the network through services. The functionality may, in turn, relate to actuation on the environment (controllingFunctionality) or sensing real world aspects (measuringFunctionality).

Figure 3. Main concepts in oneM2M Base ontology [10]

An extended semantic model has been built also as part of the COSMOS³ project (Figures 4 and 5). The model is built on three components.

Figure 4. COSMOS Information Model

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³ Cultivate resilient smart Objects for Sustainable city applicatiOnS (COSMOS), http://iot-cosmos.eu/
The core part is dedicated to modelling the main concepts and relations, which span from the topmost abstractions, the Virtual Entities (VEs) and the Group Virtual Entities (GVEs) down to the Physical Entities (PEs) and the underlying IoT services including their endpoints parameters. This part of the ontology also covers the VE and GVE location definition, providing the means to link it either to a GeoNames based location, a user defined location ontology or an external location service for mobile VEs (regarding the definition and role of VEs, more details can be found in the TagItSmart D4.1 deliverable). The third part of the semantic model consists of domain ontologies. While the core part and the social relation part of the semantic model are generic and domain independent, domain ontologies are used to link the core entities to application and domain specific descriptions. For example, if the data type (e.g. integer, double, string etc.) of a service endpoint is covered.

by the core ontology, its meaning, which is in COSMOS also a part of the description, is described using a domain ontology (e.g. temperature, traffic level, blood pressure etc.).

A number of semantic appliance models have been defined in the smart home domain. The DogOnt ontology [11] supports device and network independent description of homes, including both controllable (i.e. appliances) and structural (e.g. room, garden, garage) elements. Defined properties link these elements to their functionality, defined in terms of notification, query and control functionalities, state and communication components. The Smart Appliances REFerence (SAREF) ontology [12] has been proposed to abstract the communication protocol heterogeneity and energy profiles of appliances in the smart home domain. It contains the generic concepts derived from the semantic annotation of other assets (standards, protocols, devices, data models etc.) in the smart appliances domain. It has a core concept of a Device which represents objects found in households, public buildings and offices. Each device offers functions through associated commands. A function is presented to the network through a Service, which specifies the input and output parameters. Each device is also characterized by an Energy/Power profile to optimize energy efficiency within a building environment. The CoDaMOS ontology [13] defines a number of environmental conditions (light, temperature, humidity) and associated sensors to define rules to turn on/off actuators based on the weather (derived from the environmental conditions) and the presence of a person in the room.

### 2.3 Observation and Measurement Data models

As the next step to the semantic modelling of the physical objects of the IoT and their capabilities, it is necessary to review the information available from such resources, either as a result from their interactions or from the observation of the ambient environment. Data ontologies in the IoT mainly describe Observation and Measurement (O&M) data, mostly focusing on how data are generated, what the data are and what real world phenomena or features may be related to the data. In addition, metadata on when and where the data are generated is usually included. This section presents both data ontologies designed for annotating instantaneous and streaming O&M data.

A number of works have looked at extending the syntactic XML OGC (Open Geospatial Consortium) schemas to semantic models to link the domain knowledge to external schemas and enable cross-domain query and reasoning. Annotation of observation data with external temporal and geographical concepts using the Linked Data principles is demonstrated in [14]. In this work, observations are annotated with time (at which they occurred) and location concepts published by DBpedia\(^5\). This work does not address annotating a series of observations and its subsequent storage or querying over past data. In the Linked Sensor Middleware (LSM) and in [15], sensor data are annotated using relevant links to concepts in DBpedia and GeoNames. However, in these approaches, the focus is on provisioning the sensed data through common interfaces.

Semantic data models to manage sensor data are also presented in [16-18] with ontology models based on OGC’s O&M standard. The models defined in [16, 18] attach a time stamp to each observation using OWL-time ontology\(^6\). The key concepts modelled in the SemSOS O&M-OWL (Web Ontology Language) ontology [18] are observation, process, feature (abstraction of real-world entity) and phenomenon (property of a feature that can be sensed or measured). The observation location, result data and sampling time are also captured. The O&M concepts are aligned to SensorML and the feature and phenomenon concepts pertain to

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\(^5\) [wiki.dbpedia.org/](http://wiki.dbpedia.org/)

\(^6\) [http://www.w3.org/TR/owl-time/](http://www.w3.org/TR/owl-time/)
the weather domain. In [16], the authors retrieve observational data from a number of weather stations in the US and develop a method to convert these raw textual data into RDF (Resource Description Framework). The model captures the time, location and type attributes of the observation data. Location information is linked to concepts in GeoNames to enable answering queries related to location of sensors ‘near’ a place name. The SensorData ontology [17] defines a semantic form of the OGC SWE common data model. Each SWE data record encompasses the quantity being measured and associates it with instances of the NASA SWEET ontology\(^7\) to specify measurement units. A similar approach to separate the observations from the entity being observed is presented in the SEEK Extensible Observation Ontology (OBOE) [19], which has a core observation ontology, units extension, and a further extension for domain use (coastal ecosystems). Each observation is modelled to have a measurement, with an example provided for a coastal ecosystem domain. The concepts in the OBOE ontology would require to be extended to include generic features of possible IoT smart objects. Also, placeholders to include sensor descriptions from other ontologies would be required.

The VO (Virtual Object) ontology in [20] incorporates Information elements to represent the O&M data sensed by the VOs. Each information instance has a name and semanticURI that specifies the type of the observed feature (e.g. temperature) in terms of an instance in an external domain model, for instance, the vocabulary of climate and forecast features (CF) taxonomy\(^8\). The actual O&M data are represented through a literal value, their unit of measurement drawn from vocabularies such as the QUDV ontology\(^9\), the time the measurement was recorded and the location of measurement as specified by a geohash\(^10\) string.

As pointed out in a recent survey of WoT search techniques [21], much of the work on data streams has focused on using sensor Data Stream Management Systems (DSMS) that employ continuous queries over the data streams. However, a couple of recent works have investigated semantic annotation of sensor streams. The O&M data attributes modelled in [22] include ID, timestamp, value, unit (using the SWEET [23] ontology), datatype, location (expressed as a geohash) as well as links to external metadata (such as DBpedia and GeoNames). The Stream Annotation Ontology (SAO) [24] extends the SSN ontology’s observation concept through the StreamData class that captures segment or points of the O&M stream, linked to time intervals or time instants.

### 2.3.1 Units of Measurement Ontologies

A discussion of data ontologies is incomplete without presenting the ontology efforts for describing units of measurement that are vital for representing data measurements. Unit of Measurement (UoM) is one important aspect of smart object observation data as it helps to avoid ambiguous information from observed values and provides explicit meaning to the sensed data.

NASA’s Semantic Web for Earth and Environment Terminology (SWEET) [23] defines concepts of Representation, Realm, Phenomena, Processes, Human Activities, Matter, etc. It also defines Property, State, and Relation to express relationships between the concepts.

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Units are defined in NASA SWEET by using Unidata’s UDUnits\(^{11}\) providing conversion factors between various units [23].

Unlike NASA SWEET, W3C Quantities, Units, Dimensions and Values (QUDV) focuses more on data-related concepts. It defines modules of *Data, Unit, Scale, Quantity*, and *Dimension* for expressing values. Multiple Classes and Properties are defined under related modules for detailed expression. Focusing on terminology used in science and engineering, Quantities, Units, Dimensions and Data Types Ontologies (QUDT)\(^{12}\) aims to provide a consistent vocabulary, which can be used by both human and machines, while maintaining extensibility. In order to enable interoperability and data exchange between information systems without ambiguities, it defines three main classes of *Dimension, Quantity* and *Unit*.

The simple Units Ontology (UO) [25] is defined and classified with respect to different kinds of unit, such as acceleration unit, density unit, etc. Similarly, Ontology of Units of Measure and Related Concepts (OM) [26] also defines classes based on quantity and related kinds. An early ontological effort for representing units was the Measurement Units Ontology (MUO)\(^{13}\) that follows the Unified Code for Units of Measure (UCUM) [27], and defines basic classes such as *BaseUnit, DerivedUnit*, etc. and relationships (e.g. *derivesFrom*, *numericalValue*, etc.).

A survey of other UoM ontologies is described in [26].

### 2.4 Discussion on Related Work

A review of the entity, thing and data ontologies reveals that most research works define semantic models for a combination of these concepts, with the generic ‘thing’ concept forming a root node in most models. The common theme in these models is that they enable description of everyday connected objects, the ‘things’ in IoT, their offered functionalities and the observations (and/or effects) they make of their surrounding environment. The TagItSmart smart tag semantic model takes this as a starting point to model the smart tag observations, the associated units of measurement and the location aspects.

However, the current state of the art does not consider the concept of visible transformations in the objects in response to changing environmental conditions. The TagItSmart smart tag semantic model goes beyond the state of the art in this respect to include constructs for describing smart tags that undergo visible changes with a corresponding change in an environment feature (e.g. temperature, light) near a threshold level. The model also enables error checks for observations made for these visible changes by facilitating its association with the stated ink technology’s reversible/irreversible state.

\(^{11}\) [http://www.unidata.ucar.edu/software/udunits/](http://www.unidata.ucar.edu/software/udunits/)

\(^{12}\) [http://www.qudt.org/](http://www.qudt.org/)

\(^{13}\) [http://idi.fundacionctic.org/muo/](http://idi.fundacionctic.org/muo/)
Functional ink technologies, NFC technologies and encoding/decoding algorithms to be used in the project will be described here in detail. The properties and specifications of these technologies affect the features of the FunCodes semantic model since these technologies are a significant starting point for the technology building blocks, and are present in all scenarios utilizing FunCodes.

3.1 Ink technologies

There is a range of colour-changing technologies, the most popular and readily printable are thermochromic (changing colour with temperature) and photochromic (changing colour with ultraviolet light). Thermochromic ink is a type of ink that changes colour with heat. This can make certain images appear (or disappear) as soon as the label or product goes above or below a certain temperature. These temperatures can vary from -10 to +65 °C. For instance, the ink can show a particular temperature at which your product should be used (e.g. only drink above or below a certain temperature). Temperature-sensitive inks come in two varieties: reversible and irreversible. With reversible thermochromic ink, the colour will revert when the temperature returns to its original level. The colour remains constant after a change in temperature with irreversible thermochromic ink. However, irreversible inks are not readily available. Many photochromics and nearly all thermochromics require microencapsulation for protection.

An overview of ink manufacturers and their functional ink products are presented in Table 1.

Table 1. The overview of functional inks commercially available.

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<tr>
<th>Manufacturer</th>
<th>Thermochromic/reversible</th>
<th>Thermochromic/irreversible</th>
<th>Photochromic/reversible</th>
<th>Photochromic/irreversible</th>
<th>Fluorescent/visible</th>
<th>Fluorescent/invincible</th>
<th>Hydrochromic</th>
<th>Photo/flash activated</th>
<th>Sterilisation</th>
<th>Wee</th>
<th>Piezochromic/reversible</th>
<th>Piezochromic/irreversible</th>
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<td>Photochromic/reversible</td>
<td>Photochromic/irreversible</td>
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<td>Photoflash activated</td>
<td>Sterilisation</td>
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<td>Constantia Flexible (Spear USA Inc)</td>
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<td>B&amp;H Colour Change</td>
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<td>SafeTScribe Technologies</td>
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<td>Citronix</td>
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<td>BHC Coding Systems Ltd</td>
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<td>SFXC Special Effects and Coatings 5)</td>
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<td>Colour Changing Products</td>
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</tr>
</tbody>
</table>

1) Custom ink development
2) LCR Hallcrest: a comprehensive range of temperature labels, colour changing dyes, pigments and inks.
3) SunGuard Apollo taggart solutions visible or detectable using detection devices from laser pens to dedicated readers with controlled distribution. Hidden Indicia: a hidden image is embedded into existing product designs and only revealed through an optical lens or digital decoder such as a smartphone. Can be combined with machine readable inks to provide multi-layered authentication
4) Chinese company for development, application and promotion of smart materials: very broad range of products
5) Stocks a full range of thermochromic inks, photochromic inks, colour changing inks, colour changing paint, temperature sensitive materials, smart materials, smart paints, screen inks, screen printing, glow in the dark screen printing ink, wet and reveal ink, touch and reveal ink, heat and reveal ink as well as liquid crystal sheets. LCR Hallcrest inks.
3.1.1 Thermochromic inks

There are two predominant reversible thermochromic classes: liquid crystals and leuco dyes. **Thermochromic liquid crystals** (TLCs) change colour from black when cold, to red-orange-yellow-green-blue-violet, and then black upon heating, while the colours reverse upon cooling. TLCs are microencapsulated for protection, with a particle size of 5–50 μm in diameter. TLCs can be formulated to respond from −30 to 90°C and require a black background to appear visibly. The full colour spectrum can respond over 1°C or be as wide as 25°C. With a narrow bandwidth, the resolution is quite high, maybe 0.2°C for a 1°C wide mixture while a 25°C mixture can only resolve about a 5°C temperature. TLC inks are water-based, somewhat difficult to work with, and require such a thick coating that only screen printing is applicable. Special materials and environmental conditions are required to print them. TLCs are most effectively used by reverse printing them upon clear plastic and then protecting them with a black backing, so that they are applied in a strip form. The cost for TLC ink is typically in the €100–200 per kg range in reasonable volume.

The other type of thermochromics is called a **leuco dye** and is commonly used in manufacturing and process control, advertising, consumer packaging, product labels, security printing, novelty applications such as temperature sensitive plastics and mugs, promotional items, toys and textiles. Thermochromic leuco dyes (TLDs) change from one colour when in their cool state to translucent when in their warm state. They can be made in most colours, but not white. They are reversible but usually return to their coloured state a few degrees below the temperature that made them clear while heating. TLDs are microencapsulated and have an average diameter of 2–5 μm. TLDs can be formulated to change colour from −15 to 60°C. The transition from coloured to clear occurs over a 3–10°C range. Consequently, the materials are not suitable for most sensitive thermometer-type applications but work well for general temperature indication such as cold, warm, or hot. TLDs are dyes and not pigments, so they must be printed over a lighter background, and the background colour will influence the TLD colour if it is any colour other than white. For example, a black TLD printed over a red background would appear to change from black to red upon heating. A blue TLD printed over a yellow background would appear blue or green depending upon how thickly the blue TLD was printed, and then yellow when warm. TLDs are quite robust and can be used in a wide range of inks (solvent, water-based, UV cured, epoxy, etc.) and printed using most processes (screen, flexographic, offset, gravure, etc.). Costs for inks range from €75 for large volume screen-printing inks to €500 per kg for offset inks. Thermochromic inks are not currently used for hardcore security purposes. For example, they are not good enough for preventing counterfeiting because the inks are available for purchase on the open market.

3.1.2 Photochromic inks

Photochromics (PCs) are relatively new (1990s) compared to thermochromics (1970s), and the underlying technology continues to change rapidly. Photochromic materials change their colour when the intensity of incoming light changes. Most photochromics change from colourless to coloured upon exposure to UV light, and then fade back to colourless upon removal from the UV source. The normal wavelength of excitation is around 360 nanometers. And while sunlight works the best, a fluorescent black light, which emits near-UV light (320–400 nm), will usually work. There is a full spectrum of photochromic colours available. Different PC dyes have different kinetics, meaning some will colour and fade quickly, while others will colour and then fade slowly.

The raw PC dyes tend to be quite expensive, ranging from €3 per gram to over €200 per gram. However, they are often used in low concentrations (0.2–1% by weight). Typical inks are
expensive, ranging from €100 to over €500 per kg. Very few PC dyes are water-soluble, so for waterborne applications microencapsulation is required. For many non-aqueous inks, microencapsulation is often preferable because it protects the PC dyes. The same unique nature that allows PC dyes to change colour makes them inherently unstable. Lifetimes for the photochromic dyes can be as short as 1 hour outside without stabilizers. With a stabilization package, lifetimes of about 1 month of outdoor exposure are possible. Because the PCs are dyes, they are most effective on white or very light backgrounds.

3.1.3 Other functional inks

In addition to thermochromic and photochromic inks there are several other functional ink types on the market. Examples of various other ink types on the market are:

- Invisible fluorescent inks and varnishes can only be seen under UV or IR light. The fluorescent particles in the ink absorb the UV/IR light and then reflect it.
- Phosphorescent ink glows in the dark after it has been exposed to a source of light. The phosphor particles in the ink are capable of absorbing light and then releasing it after a certain time.
- Solvatochromism depends on the particular interaction between the molecules of the substance and the molecules of the solvent. The substance which contains chromophore groups is sensitive to the polarity of the solvent, which functions like a constant electrical field and determines the effects on the spectroscopic properties of the substance, hence a change in colour.
- Hydrochromic ink is a type of ink that changes colour if water has been applied. It is a special white ink, which changes repeatedly from white to transparent when wetted with water and changes back to the original white when dried. The vivid colour design is concealed with white in dried condition and appears when the ink becomes transparent with water.
- Laser-markable ink is used for surfaces which can be overprinted later using a low-energy laser. Applying a laser beam changes the colour of the laser-markable ink and allows a code or image to become visible on the printed surface.
- Scratch-off ink, as the name suggests, is ink that has to be scratched or scraped away. The message, which can be printed in various colours, is hidden beneath a top layer that is printed in e.g. silver or gold colour.
- Black IR inks prevent forgery of barcodes by photocopying.
- Magnetic inks are used as guiding and detection inks in connection with a magnetization reading device. Can be used for tickets, for checking authenticity.
- Conductive inks are inks with high electrical resistance. Can be used as security inks with a special electrical pen or as a guiding-ink for digital signals. Can be used for tickets, for checking authenticity.
- Coin inks turn visible when rubbed with a coin.
- OVS (Optical Variable Shade) change colour according to angle of viewing. Can be colour changing, sparkling, metallic, pearlescent.
- Tactile/effect ink.
- Prismatic effect ink. Provides a holographic effect. Can be used for security & brand protection.
- Holographic ink brings a new and innovative label effect. Image is created via a printing plate.
- Touch’n Smell inks are based on an aroma that is released when the printed surface is rubbed with a finger.
3.1.4 Intelligent systems in food packaging

Intelligent packaging represents a big step forward to improve food safety, logistics, and traceability. The term “intelligent” involves an “ON/OFF” switching function on the package in response to changing external/internal stimuli, in order to communicate the product's status to its consumers or end users (Yam et al. 2005). In practice, an intelligent packaging system is manufactured by incorporating an external, discrete component in the final package, e.g., two-dimensional films or three-dimensional objects. It is widely accepted that intelligent packaging systems can be realized by three main technologies: (i) indicators, which aim to provide more convenience and/or to inform consumers about the food quality; (ii) sensors, which allow for a rapid and definite quantification of the analytes in foods, and (iii) data carriers, such as barcodes and radiofrequency identification tags (RFID), which are specifically intended for storage, distribution, and traceability purposes.

3.1.4.1 Indicators

Indicators inform about a change occurred in a product or its environment (e.g. temperature, pH) by means of visual changes. Most often, the information is displayed by immediate visual changes, e.g., different colour intensities or the diffusion of a dye along the indicator geometry. A distinct feature of indicators is the type of information involved, which is qualitative or semi-quantitative in nature. Indicators with application to food packaging are time temperature indicators, oxygen and integrity indicators and freshness indicators.

3.1.4.2 Temperature indicators

There are two types of temperature indicators: simple temperature indicators and time-temperature integrators (TTIs). Temperature indicators show whether products have been heated above or cooled below a reference (critical) temperature, warning consumers about the potential survival of micro-organisms and protein denaturation during, for example, freezing or defrosting processes.

TTIs, sometimes also called integrators, are the first generation of indicators intended to monitor any detrimental change in temperature (e.g. above or below a reference critical value) along the food supply chain, i.e., over time. The basic operating principle is based on mechanical, chemical, electrochemical, enzymatic or microbiological change, usually expressed as a visible response in the form of a mechanical deformation, colour development or colour movement (Taoukis and Labuza, 2003). Due to the role of both time and temperature in influencing the kinetics of physical and chemical deterioration, TTIs have gained increasing interest for acquiring information about the temperature history of a packaged food over time, thus preventing any sort of abuse and/or misuse. TTIs are recognized as user-friendly and readily usable devices, whose information is readily understood by consumers as being directly related to the quality of the food item at a certain temperature. Usually, they consist of small, self-adhesive labels attached to single packages or larger configurations (e.g., containers).

TTIs’ market applications are listed in Table 2. Several other examples of TTIs are still in the laboratory stage.

Table 2. Existing market application of TTIs.

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Type of indicator of indicator</th>
<th>Image</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monitor Mark™ by 3M (USA)</td>
<td>diffusion</td>
<td></td>
</tr>
<tr>
<td>(<a href="http://solutions.3m.co.uk/wps/portal/3M/en_GB/FoodSafetyEU/FoodSafety/ProductApplications/TemperatureMonitoring/">http://solutions.3m.co.uk/wps/portal/3M/en_GB/FoodSafetyEU/FoodSafety/ProductApplications/TemperatureMonitoring/</a>)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Checkpoint® by Vitsab International AB (Sweden)</td>
<td>enzymatic</td>
<td></td>
</tr>
<tr>
<td>(<a href="http://vitsab.com/">http://vitsab.com/</a>)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CoolVu™ by Freshpoint (Israel)</td>
<td>corrosion</td>
<td></td>
</tr>
<tr>
<td>(<a href="http://www.freshpoint-tti.com/">http://www.freshpoint-tti.com/</a>)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OnVu™ by Freshpoint (Israel)</td>
<td>photochemical /oxidation</td>
<td></td>
</tr>
<tr>
<td>(<a href="http://www.freshpoint-tti.com/">http://www.freshpoint-tti.com/</a>)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fresh-Check® by TempTime (USA), earlier Lifelines Technologies Inc.</td>
<td>polymerisation</td>
<td></td>
</tr>
<tr>
<td>(<a href="http://temptimecorp.com/">http://temptimecorp.com/</a>)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tempix® by Tempix AB (Sweden)</td>
<td>diffusion, melting</td>
<td></td>
</tr>
<tr>
<td>(<a href="http://tempix.se/">http://tempix.se/</a>)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Timestrip® by Timestrip Plc (UK)</td>
<td>diffusion</td>
<td></td>
</tr>
<tr>
<td>(<a href="http://timestrip.com/">http://timestrip.com/</a>)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FreshCode by Varcode (US)</td>
<td>chemical process</td>
<td></td>
</tr>
<tr>
<td>(<a href="http://www.varcode.com/">http://www.varcode.com/</a>)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Keep-it by Keep-it Technologies (Norway), formerly TimeTemp</td>
<td>diffusion</td>
<td></td>
</tr>
<tr>
<td>(<a href="http://www.keep-it.no/">http://www.keep-it.no/</a>)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Insignia Cold Inspection Intelligent Labels™ by Insignia Technologies Ltd (UK)</td>
<td></td>
<td></td>
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<tr>
<td>(<a href="http://insigniatechnologies.com/">http://insigniatechnologies.com/</a>)</td>
<td></td>
<td></td>
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<tr>
<td>ThermoTrace, distributed by Deltatrak (US), produced by Varcode</td>
<td></td>
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<tr>
<td>(<a href="http://www.deltatrak.com/products/time-temperature-indicator-label">http://www.deltatrak.com/products/time-temperature-indicator-label</a>)</td>
<td></td>
<td></td>
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<tr>
<td>TempDot by Deltatrak (US), same as Timestrip</td>
<td>diffusion</td>
<td></td>
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<tr>
<td>(<a href="http://www.deltatrak.com/products/time-temperature-indicator-label">http://www.deltatrak.com/products/time-temperature-indicator-label</a>)</td>
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### Gas indicators – integrity indicators

Gas concentration indicators, in the form of labels, are placed inside the package to monitor changes in the inside atmosphere due to permeation phenomena across the packaging material, microorganisms metabolism, and enzymatic or chemical reactions on the food matrix. Gas indicators are also used to either assess the efficacy of active packaging components (e.g., O₂ and CO₂ scavengers) or to detect the occurrence of leakages.

Among the various types of gas indicators, oxygen indicators are the most common indicators used for MAP packaging applications. MAP gases usually consist of high levels of carbon dioxide or nitrogen and a residual concentration of O₂ (0.1–1%). Therefore, a leak in a MAP package will be easily detected using indicators of the level of oxygen. A well-known trade name of a gas indicator application is Ageless Eye™ by Mitsubishi Gas Chemical Co. This are other examples of gas indicators are listed in Table 3.

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Type of indicator</th>
<th>Image</th>
</tr>
</thead>
<tbody>
<tr>
<td>TI Indicator by Temperature Indicators Ltd (UK) (<a href="http://temperature-indicators.co.uk/">http://temperature-indicators.co.uk/</a>)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>It’sFresh by It’s Fresh! Ltd (UK) (<a href="http://www.foodfreshnesstechnology.com/group-companies-2/itsfresh/">http://www.foodfreshnesstechnology.com/group-companies-2/itsfresh/</a>)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TT Sensor Plus™ by Avery Dennison Corporation (US) (<a href="http://label.averydennison.com/en/home/lpm-products/key-label-innovations/TT-sensor-plus.html">http://label.averydennison.com/en/home/lpm-products/key-label-innovations/TT-sensor-plus.html</a>)</td>
<td>data is stored in a chip</td>
<td></td>
</tr>
<tr>
<td>Topcryo ® TTI by Cryolog, (France) (<a href="http://cryolog.com/en/">http://cryolog.com/en/</a>)</td>
<td>microbiological</td>
<td></td>
</tr>
<tr>
<td>MagicAdd (Finland) (<a href="http://www.magicadd.com/">http://www.magicadd.com/</a>)</td>
<td>temperature sensitive QR code</td>
<td></td>
</tr>
</tbody>
</table>

**Table 3. Commercial examples of gas indicators.**

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Type of indicator</th>
<th>Image</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ageless Eye by Mitsubishi Gas Chemical Inc. (<a href="http://www.mgc.co.jp/eng/products/abc/ageless/eye.html">http://www.mgc.co.jp/eng/products/abc/ageless/eye.html</a>)</td>
<td>O₂ indicator tablet</td>
<td></td>
</tr>
</tbody>
</table>
The simplest integrity indicators are time indicators that provide information about how long a product has been opened. The label is activated at the moment of consumption, when the seal is broken it triggers a timer and experiences a colour change with time. Some commercial examples are Timestrip® (Timestrip Ltd.) and Insignia After Opening Freshness Timer Intelligent Labels™ (Insignia Technologies Ltd.) listed in Table 4.

### Table 4. Commercial examples of time indicators.

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Type of indicator</th>
<th>Image</th>
</tr>
</thead>
<tbody>
<tr>
<td>Timestrip® by Timestrip Ltd. (UK) (<a href="http://timestrip.com/">http://timestrip.com/</a>)</td>
<td>Time indicator label</td>
<td><img src="image" alt="Timestrip" /></td>
</tr>
<tr>
<td>After Opening Freshness Timer Intelligent Labels™ by Insignia Label (<a href="http://insigniatechnologies.com/index.asp">http://insigniatechnologies.com/index.asp</a>)</td>
<td>based on CO₂ detection</td>
<td><img src="image" alt="Insignia" /></td>
</tr>
</tbody>
</table>

### 3.1.4.4 Freshness indicators

The idea of freshness indicators is that they monitor the quality of the packed food by reacting in one way or another to changes taking place in the fresh food product as a result of microbial growth or metabolism. Intelligent packaging systems for monitoring food freshness are found either as freshness indicators based on an indirect detection of metabolites through colour indicators (e.g. pH) or based on direct detection of target metabolites using biosensors. For example, freshness indicators intended for seafood are based on volatile amines, which are formed as the food spoils. Hydrogen sulfide indicators can be used to determine the quality of meat products. Smolander et al. developed a freshness indicator based on this principle for modified atmosphere packed poultry meat [28]. Other freshness indicators are based on sensitivity toward other microbial metabolites, such as ethanol, diacetyl, and carbon dioxide.

The ripeness indicator RipeSense™ allows consumers to choose fruit that best appeals to their tastes by detecting aroma components or gases involved in the ripening process (e.g., ethylene) released by the fruit. Freshness indicators such as ToxinGuard® by Toxin Alert Inc., to monitor Pseudomonas sp. growth, and SensorQ™ by FQSI Inc., which senses spoilage in...
Fresh meat and poultry products as well as Raflatac indicators and Food Sentinel System are currently not commercially available at the moment. Freshness indicators are listed in Table 5.

### Table 5. Commercial examples of freshness indicators.

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Type of indicator</th>
<th>Image</th>
</tr>
</thead>
<tbody>
<tr>
<td>RipeSense® by Ripesense Limited (NZ) (<a href="http://www.ripesense.co.nz/">http://www.ripesense.co.nz/</a>)</td>
<td>ripeness indicator</td>
<td><img src="image1.png" alt="Image" /></td>
</tr>
<tr>
<td>It'sFresh by It's Fresh! Ltd (UK) (<a href="http://www.foodfreshnesstechnology.com/group-companies-2/itsfresh/">http://www.foodfreshnesstechnology.com/group-companies-2/itsfresh/</a>)</td>
<td>detects gases produced by microbes</td>
<td><img src="image2.png" alt="Image" /></td>
</tr>
<tr>
<td>SensorQ® by DSM NV and Food Quality Sensor International Inc. No available?</td>
<td>pH sensing indicator</td>
<td><img src="image3.png" alt="Image" /></td>
</tr>
<tr>
<td>Raflatac by VTT and UPM Raflatac Not in production</td>
<td>Colorimetric indicator</td>
<td></td>
</tr>
<tr>
<td>Food Sentinel System by SIRA Technologies Inc Not anymore?</td>
<td>Biosensor (barcode)</td>
<td></td>
</tr>
<tr>
<td>Toxin Guard® by Toxin Alert Inc. Not anymore?</td>
<td>Biosensor (film)</td>
<td></td>
</tr>
</tbody>
</table>

### 3.2 NFC properties

There are many NFC technologies available, because the field is quite big. This section will focus on Thinfilm’s NFC technologies since those are the ones that will be used in the project. This also serves as a better starting point for the semantic model when the focus is on specific NFC properties.

Near field communication (NFC) is a short-range, smartphone-readable form of Radio Frequency ID (RFID) technology that operates at a standard carrier frequency of 13.56MHz. NFC transmissions typically span a few centimetres (0-4 cm), which allows for a secure link between two NFC capable devices. Furthermore, this read distance is optimized to enable very ‘intentional’ actions, where the user is fully in control of which item they will select for interaction. This contrasts with long-range wireless communication technologies, such as Bluetooth and UHF RFID technology, where many items are often simultaneously inside the read distance boundary and therefore subject to confusion and/or user requests for intervention/manual selection.

NFC technology is included in more than one billion smartphones in use worldwide. It provides a common link between use cases ranging from mobile payments and public transportation to pairing/sharing and tag reading. In short, NFC allows a smartphone to be used as a precision gateway from the physical world’s electronic devices and everyday objects to the multimedia extensions of those items in the digital world. Studies have shown that consumers prefer NFC technology based on its speed, convenience, and preservation of user control.
NFC tags printed by Thinfilm are typically take the form of thin, flexible, self-adhesive labels. These passive (no battery required) labels – sometimes also referred to as “NFC tags” – consist of the three parts: the printed integrated circuit (PIC), an antenna to enable both energy harvesting and wireless data transmission, and optional sensors. When Thinfilm prints each IC, it is encoded with a unique identifier that can be used to identify each specific instance of a product, rather than simply a product category or product type. This item-level identification allows for precision track & trace applications in addition to personalized consumer marketing. Thinfilm NFC tags typically contain unique identifiers that are 128 bits in length.

In addition to each tag’s unique identifier, NFC tags can be integrated with sensors, such as Thinfilm’s NFC OpenSense™ technology, to act as a smartphone-readable electronic seal that can help ensure package authenticity and integrity while fighting return fraud and the fraudulent refill of empty packages. With time, other sensors can be integrated into the NFC tag. Temperature sensors can be used together with thin, flexible printed batteries to track the condition of a temperature-sensitive shipment and alert the logistics provider, insurance company, and/or recipient – at the item level – when a sensitive shipment was exposed to abnormal conditions. This data has two purposes: individually, it helps the recipient to understand whether a product is safe to use, and in aggregate, it helps brands and logistics providers to identify trends and patterns in order to continually improve supply chain integrity.

NFC tags can be integrated into a wide variety of product and package shapes because they are thin, flexible, and compatible with curved surfaces. When the decision maker prefers a visible tag, NFC tags can be applied as full-colour, self-adhesive graphic labels. When the decision maker prefers an invisible tag, the NFC label can be completely hidden between layers of paper or adhered to the inside of the product or package. Unlike camera-based technology, NFC uses RF technology that can pass through surfaces including, glass, plastic, paper, cardboard, and wood. It requires no line of sight or special lighting to achieve maximum performance.

Unlike camera-based technologies, which can consume significant processing power when running continuously, NFC smartphones use a minimal amount of power to continuously scan when the phone is active. Smartphone operating systems such as Android and Windows support NFC tag reading either with or without any specific scanner app. The NFC read functionality is built directly into the operating system itself. This means that a consumer or other user can take an ordinary off-the-shelf NFC phone, without special preparation or pre-installation of apps, and launch a digital experience by simply touching that phone to a compatible NFC tag. In cases where the brand or application owner uses mobile apps as part of their strategy, NFC tag reading can be easily integrated into those apps using existing APIs provided by the mobile operating system.

NFC technology can be used to enhance a wide variety of applications. Unlike UHF RFID technologies, NFC’s 13.56MHz wireless technology can be reliably read in the presence of liquids such as water. Like other RFID technologies, operation near metal surfaces requires special care. Like other technologies, NFC signals cannot pass through solid metal, so integrators should take care to avoid situations where sheets of metal block the path between the NFC tag and reader. When a metal object or package requires an NFC tag, a special shielding material (such as ferrite) or even a modest air gap can preserve the NFC tag’s RF performance.

3.3 Encoding and decoding mechanisms
3.3.1 Datamatrix SmartTag

When a datamatrix tag is used, SmartTag takes advantage of the standards on datamatrix encoding mechanism. This makes possible scanning SmartTAGs with any datamatrix standard compatible device. SmartTAG contents (unique identifier which might be prefixed with URL) are encoded into a datamatrix as the standard specifies. This applies also to decoding; content is read from the SmartTag as it is from any other datamatrix tag.

Using the datamatrix standard it is not possibly to capture sensor information. SmartTag encodes sensor information into a datamatrix by taking advantage of the datamatrix error-correction capabilities. SmartTag specifies defined location for sensor data cells. These locations (and their count) depend on the datamatrix code size. When a SmartTag is decoded in a proper way, a TagItSmart compatible scanner can extract sensor data from the tag by looking into certain locations of the SmartTag.

Figure 6 Example of datamatrix (https://en.wikipedia.org/wiki/Data_Matrix)

Figure 6 illustrates a standard datamatrix tag of size 16x16, colours in figure mark different functional areas:

1. Violet is the datamatrix locating pattern which is solid in left and bottom edges and alternating black – white in top and right edges
2. Greens are data areas
3. Yellows are padding
4. Reds are error correction
5. Orange is not used

Each area (except locating pattern and the unused area) consists from eight binary (black/white) cells. Eight cells make up one block which contains either data, error correction data or padding.

A SmartTag takes advantage of the datamatrix error correction capacity by utilising some percentage of possible error correction capacity for sensor data. These sensor data vary between different sizes of the datamatrix. For different sizes, a variable amount of sensor cells are used to replace error correction cells.

As replacing error correction cells with sensor data reduces the capability to correct possible errors in the decoding process, the placement of sensor data is done by placement charts. This ensures that a datamatrix is still readable and that sensor data can be looked up without having to do heavy calculation while decoding or connecting to a server.
To ensure that sensor data can be decoded and analysed offline, reference colours are inserted into a finder pattern. These reference colours represent sensors values in both states minimum and maximum.

### 3.3.2 QR code SmartTaG

Creation of a SmartTag is done by generating numeric values into the QR code. Accordingly, instead of using standard linear barcode format and in order to allow functional ink to change its structure – alphanumeric values are encoded into the QR code.

The data format for functional codes generated as a QR code are given as a sequence of 25 alphanumeric characters, where part of it represents product, product line and sensor measurements. The amount of information that could be encoded depends on the version of used QR code; in this particular case Version 1 (21x21 bit) is used which supports up to 25 alphanumeric characters which is in total 208 bits (152 bits for data and 56 bits for error correction).

The example of one dataset that could be used to generate QR code is as follows:

| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 2 | 2 | 3 | 4 | 5 |
| V | L | Y | Y | S | W | D | H | D | 8 | M | 4 | Y | 0 | 0 | 1 | 9 | P | R | T | O | 0 | 0 | 0 |

Where alphanumeric group meanings for values are:
- Code for product (from 1-15)
- Code for product line (from 16-22)
- Code for sensor value (23 - 25)

The QR code generated from this example (Figure 7) represents 25 alphanumeric characters with embedded sensor measurement value that is printed with functional ink (marked in red and blue colour).

![QR Code Example](image)

**Figure 7. QR code example with embedded data about product, product line and part printed with functional ink (red and blue)**

An Error correction field will be used to read the initial state of the sensors measurements and product data and it will be printed with functional ink in order to change the structure of the matrix according to extracted values.
Functional ink will disappear (red and blue part of QR code) when a threshold predefined value is reached and it will change the structure of the QR code (Figure 8). After this change, the data encoded in QR also changes and they will have different value (e.g. VLYYS8WDH8M4Y0219PRTQ011)

Figure 8. QR code example with the fields that are changed (red and blue)

After functional ink changes its state, if the QR code is scanned again the alphanumeric text changes its value. The example is given below:

- VLYYS8WDH8M4Y0219PRTQ2%0 – if red field disappears (Figure 8)
- VLYYS8WDH8M4Y0219PRTQ080 – if blue field disappears (Figure 8)
- VLYYS8WDH8M4Y0219PRTQ310 – if both read and blue fields disappear (Figure 8)
Section 4 - Requirements for functional codes model

In this section we first give the general requirements that drive the design of the SmartTag semantic model. Then we give some very use case specific requirements, which eventually influence the selection of technologies used for creating SmartTags for them as well as the use of classes and properties of the SmartTag model (see also section 5) for use case specific “instantiations” of that model.

4.1 General requirements

This section describes the requirements identified for the SmartTag model based on the functional inks and NFC properties specified in the preceding section, as well as those derived from the encoding, decoding mechanisms applicable to the SmartTag creation and scanning processes, respectively. Requirements specific to the TagItSmart use cases, as defined in D1.1, are also captured here. Each identified requirement is marked as functional or non-functional.

Table 6. SmartTag model: general requirements

<table>
<thead>
<tr>
<th>ID</th>
<th>Requirement</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>ST-1</td>
<td>A SmartTag must have a unique identification</td>
<td>Non-Functional</td>
</tr>
<tr>
<td>ST-2</td>
<td>A SmartTag model must describe the capabilities of the SmartTag</td>
<td>Functional</td>
</tr>
<tr>
<td>ST-3</td>
<td>A SmartTag must depict the reactions to chemical/physical conditions of the constituent functional inks</td>
<td>Functional</td>
</tr>
<tr>
<td>ST-4</td>
<td>The permissible reaction states (reversible/permanent) of the functional inks should be described.</td>
<td>Functional</td>
</tr>
<tr>
<td>ST-5</td>
<td>The properties of the functional inks should be described.</td>
<td>Functional</td>
</tr>
<tr>
<td>ST-6</td>
<td>The properties of the NFC should be described, where the SmartTag is of a printed electronic type</td>
<td>Functional</td>
</tr>
<tr>
<td>ST-7</td>
<td>The SmartTag should enable a means to describe the observations recorded with each scan of the tag</td>
<td>Functional</td>
</tr>
<tr>
<td>ST-8</td>
<td>The recorded observations should contain contextual information such as location, time etc.</td>
<td>Functional</td>
</tr>
<tr>
<td>ST-9</td>
<td>SmartTag evolution must be traceable and referenceable</td>
<td>Non-Functional</td>
</tr>
<tr>
<td>ST-10</td>
<td>SmartTag descriptions must be semantically enhanced and linked-data capable</td>
<td>Non-Functional</td>
</tr>
<tr>
<td>ST-11</td>
<td>SmartTag descriptions must be extendable and allow further enrichment</td>
<td>Non-Functional</td>
</tr>
<tr>
<td>ID</td>
<td>Requirement</td>
<td>Type</td>
</tr>
<tr>
<td>------</td>
<td>-----------------------------------------------------------------------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>ST-12</td>
<td>SmartTags descriptions should be dynamic, with updates possible over the lifecycle of the SmartTag.</td>
<td>Non-Functional</td>
</tr>
</tbody>
</table>

### 4.2 Digital products use case

In the digital products use case, a functional code has two functions, to give unique identifier for each bottle and to tell the actor the optimal drinking temperature. Both of these functions must be encoded into the same datamatrix tag and preferably be readable with most popular datamatrix scanners (mobile) available, although it is acceptable that sensor information is only readable by devices/programs that are only TagItSmart compatible.

When it comes to SmartTag relation to datamatrix standard, a SmartTag should not break the standard in a way that makes it impossible to use existing datamatrix scanners for reading information (identifier info) from SmartTag. But as embedding sensors into a SmartTag is new technology it is acceptable that a SmartTag “extends” datamatrix standard in a defined way.

UPC will use reversible (green) thermochromic ink (+8 Celsius) in the Digital Products use case. This temperature is ideal for beer. If a SmartTag sensor indicates temperature higher than +8 Celsius (it will be invisible), it will handled as an “error” in this use case.

Digital products use case considers very tight physical requirements. In pilot phase SmartTAG should not exceed size 1.8cm x 1.8cm and should be readable in under 2 seconds. In the end of the project the goal is to use 1.0 cm x 1.0 cm size SmartTag, also in the other use cases.

### 4.3 Lifecycle management use case

Lifecycle management use case uses functional QR codes printed with an irreversible thermochromic ink that changes colour at -13°C after 30 minutes, and NFC tags containing high temperature proof.

### 4.4 Brand protection use case

Brand protection use case is based on photochromic inks reacting to camera flash. The QR code is printed with regular inks and two photochromic inks (parts of code). One of the photochromic ink changes from colour to invisible (disappearing) when exposed to camera flash, while the other photochromic ink changes from invisible to colour (appearing). The colour changes are reversible.

### 4.5 Dynamic pricing use case

The dynamic pricing use case utilizes irreversible thermochromic inks or time-temperature indicators. The colour change from black to red should occur at +7°C after 30 minutes.

### 4.6 Home services use case

The home services use case utilizes several irreversible functional inks and also NFC tags. The functional inks are:
• Time elapse indicators for 3 months and 11 months,
• Thermochromic inks with colour change at +50 °C,
• Hydrochromic inks reacting at contact with water,
• Ink reactive to carbon monoxide concentration above 50 ppm,
• Photochromic ink.
Section 5 - SmartTag semantic model overview

Following the listing of functional inks and NFC properties as influencing the SmartTag description in section 3, and the requirements gathered in section 4, this section describes the constituent classes and properties of the resultant SmartTag semantic model as defined to meet the requirements of the TagItSmart platform architecture and use case scenarios.

The semantic model has been developed in the OWL-DL (Web Ontology Language – Description Logics) language, which is the second OWL sub-language (the others being OWL-Lite and OWL-Full) and is based on Description Logics, the decidable fragment of first order logic and therefore, enables automated reasoning. It is therefore, possible to automatically compute the classification hierarchy and check for inconsistencies in an ontology written in OWL-DL.

Following the ontology design principles of reusing and extending existing ontologies [29], the SmartTag ontology makes use of some classes and properties from the following ontologies that are imported into the SmartTag semantic model:

- Measurement Units Ontology (MUO) that follows the Unified Code for Units of Measure (UCUM) to describe the units of measurement for the measurements recorded by the SmartTags as well as the threshold values for the allowed state changes of the tags.
- CoDaMOS ontology – the environmental conditions class and its sub-classes of Lighting, Temperature are used to describe the environment features to which the different sub-classes of dynamic inks, i.e. thermochromic or photochromic inks react to. The environmental conditions class is also extended with a new sub-class of Carbon_Monoxide_Level to constrain the environment feature description for CO_Reactive inks.

Moreover, in accordance with the Linked Data principles [30], the SmartTag ontology includes properties that allow linking to instances in external domain ontologies, for instance, global location URI of a SmartTag observation links to the relevant location instance in the GeoNames ontology, where the given location is more fully described.

The TagItSmart SmartTag model is shown in Figure 9. Each SmartTag instance is specified by its unique identifier (hasID property, defined through an URI) and a name defined as a string literal value. The semantic model for SmartTags enables representation of both printed electronics (e.g. NFC labels) and passive printed 2-dimensional tags such as datamatrix and QR codes. This is represented through corresponding sub-classes by employing the <owl:subclassOf> hierarchical representation, with each class capturing the specific properties of the SmartTag type.

The information embedded in the SmartTags can be retrieved by applying the appropriate decoding mechanism, as specified through the requiresDecodingMechanism object property to the DecodingMechanism class. Each decoding mechanism also has a literal name and URI and is further specified by linking to the Scanner class through the usesScanner property to describe the required scanner and its properties.

Each passive printed SmartTag also features an encoding mechanism that is described in the EncodingMechanism class. Since the TagItSmart project extends the current standard encoding mechanisms with innovative features that are currently being tested, the EncodingMechanism class is currently a place-holder for properties that will be defined once the encoding mechanisms have matured.
Each SmartTag maintains a record of the scanned measurements by instantiating an object of the Observation class, which includes a literal name (obs_name), URI (linking to an external domain model instance that specifies the environmental feature being observed, e.g. temperature), (string) description (what the observation is about), type (obs_Type) and the time of the scan (obs_Time property specified in terms of an owl:dateTime instance). Each observation record also includes location context information, which is represented by an instance of the Location class. Location is specified through the WGS84 [31] Point specification for latitude (hasLatitude) and longitude (hasLongitude), a global location (hasGlobalLocation) specified by linking to an instance in the GeoNames ontology, which could represent certain well-known landmarks or buildings, the city/town or country and also relative location within an indoor location model (hasLocalLocation property).

Each observation also captures the lifecycle state of the SmartTag, through the LifecycleState class. The LifecycleState class is defined as an enumerated class, which implies that it is a class of the instances, (and only the instances) listed in the enumeration. In this case, the allowed states and hence the instances of the class are: Reversible | Irreversible | Open | Sealed | Tampered. The first 2 instances refer to the allowed states for dynamic inks and the latter 3 to those for NFC tags, as described in section 3.2. In DL notation, the LifecycleState class is represented as:

\[
\text{LifecycleState} \equiv \{\text{Reversible Irreversible Open Sealed Tampered}\} \tag{1}
\]

The equivalence (≡) symbol in (1) formally defines the LifecycleState class to be equivalent to (contains the same instances as) the anonymous class that is defined by the enumeration.

As the passive tags can be encoded using functional inks that react dynamically to changing environmental conditions, the related properties are captured in the DynamicInk class that is associated to the QR-code or Datamatrix instance through the usesInk property. Each DynamicInk class instance is described using the ink features, which could include reaction times, shelf life etc. specification for the corresponding ink.

Inks could be thermochromic, hydrochromic or fluorescent visible/invisible, as described in section 3.1 and these different aspects are represented through corresponding sub-classes of the DynamicInk class. The environment feature that these different inks respond to is described by the reactsTo property and by placing relevant restrictions on the property range depending on the sub-class. For instance, for the thermochromic ink sub-class, both the existential quantifier (Ǝ) and universal quantifier (∀) are attached to the reactsTo property with the codamos:Temperature class of instances as the restriction filler. This is denoted in DL notation in (2):

\[
\text{Thermochromic} \sqsubset \text{Ink}. \text{reactsTo} \ Ǝ \text{codamos:Temperature} \\
\text{Thermochromic} \sqsubset \text{Ink}. \text{reactsTo} \ ∀ \text{codamos:Temperature} \tag{2}
\]

The existential restriction specifies the existence of a (i.e. at least 1) relationship along the specified property to instances of the specified class. In other words, reactsTo Ǝ codamos:Temperature describes all instances that have at least 1 reactsTo property relationship to an instance of the codamos:Temperature class. However, due to OWL-DL’s open world assumption, a reasoner can assume that instances of the class Thermochromic – Ink can have reactsTo relationships to instances of other classes. Thus, we add a closure axiom to the property with the universal quantifier restriction which constrains the property range to instances of only the specified class. Thus, a Thermochromic – Ink class is now defined as one which has at least one reactsTo property to a
codamos:Temperature class instance and also only to that instance of the codamos:Temperature class.

An important aspect of the inks are the colour and visibility changes at certain environmental condition changes. This is described through the State-Change class, which is linked to the DynamicInk class through the hasAllowedStateChange property. The visible transformations inherent in a state change are defined by linking the hasVisibleTransformation property from the State-Change class to the Colour-Change class. The Colour-Change class describes 2 properties: fromColour and toColour, with both property ranges defined as instances of the Ink-Colour class. Similar to the LifecycleState class, the Ink-Colour class is defined as an enumerated class, constraining it to only the defined instances, as shown in (3) below:

\[
\text{Ink} - \text{Colour} \equiv \{\text{Red}, \text{Green}, \text{Yellow}, \text{Black}, \text{Visible}, \text{Invisible}\}
\]  

The allowed colour instances have been defined based on the ink properties described in section 3.1; more instances can be defined in the ontology if inks with other colour properties are used during the course of the project.

Attaching both existential and universal quantifiers to the hasVisibleTransformation property ensures that each state change has at least one colour or visibility change and the change is only in terms of the defined colours.

The threshold value at which the colour (or visibility) change occurs is described through the occursAtThreshold property to the Threshold class, which in turn defines a threshold value (hasThresholdValue) (as a double) and an associated unit of measurement (thresholdUoM) defined in terms of an instance of the MUO ontology. Placing the universal quantifier restriction on the occursAtThreshold property, as shown in (4), ensures that the allowed threshold property values are only to instances of the Threshold class, but it also allows for an instance of the State-Change class not to have any occursAtThreshold property assertions, since the universal quantifier states that if the property exists, it must be to the defined property range. This applies to the Hydrochromic class which undergoes a visible transformation just in the presence of water; and not at a specific threshold value.

\[
\text{State} - \text{Change.occursAtThreshold} \forall \text{Threshold}
\]  

The time delay information is described with the hasTimeDelay property between the State-Change and the TimeLapse class. The TimeLapse class has a timelapse value (timelapseValue as an integer) and an associated unit of measurement (timeLapseUoM). The values for the unit of measurement are constrained to instances of the MUO ontology by the existential quantifier, as shown in (5):

\[
\text{Time} - \text{Lapse.timeLapseUoM} \exists \text{muo:UnitOfMeasurement}
\]  

Similar to the Threshold class, a universal quantifier restriction on the hasTimeDelay property ensures that this property is only instantiated by inks that have a time lapse associated with their state change, while instances that do not have this property assertion also fulfil the class definition.

The ontology ensures that each dynamic ink class instance has at least one state change by the existential quantifier and also constrains the definition to this class by adding a closure axiom by the universal quantifier, as shown in (6).
A similar existential and closure axiom is defined for the `hasAllowedLifecycleState` property linking the `DynamicInk` and `LifecycleState` classes.

To reflect the current development of NFC tags within the project, the SmartTag ontology associates each NFC class with the `LifecycleState` class through the `hasAllowedLifecycleState` property. Thus, the same `hasAllowedLifecycleState` property is used for both NFC tags and those printed using dynamic inks by specifying the domain of the `hasAllowedLifecycleState` property to be the union of the `DynamicInk` and `NFCTag` classes, as shown in (7) (only the existential restriction is shown):

\[
(DynamicInk \cup \text{NFCTag}).\text{hasAllowedLifecycleState} \exists \text{State} \rightarrow \text{Change}
\]  

(7)

Since the NFC tags are also proposed to have other sensors during the course of the project (in addition to the current ones which detect one of the open/sealed/tampered states), such as temperature, this can also be seamlessly described in the ontology by linking the `NFCTag` class to the `State-Change` class through the `hasAllowedStateChange` property.
Section 6 - Conclusions and future work

This deliverable presents the first version of the SmartTag ontology developed in the TagItSmart project, with formal definitions of the constituent classes, properties and ontology restrictions. To support the recognition of the required class properties and restrictions, the characteristics of the ink technologies used to produce the SmartTags and NFC properties have been detailed in section 3. The relevant state of the art in related works on contextual QR codes and semantic model definitions for devices and sensors in the wider IoT area have been presented in section 2.

The analysis of the existing works and the ink technology properties have led to the identification of the requirements for the SmartTag model. This has been further refined by identifying requirements specific to the different use cases; these generally take the form of the allowed visible transformations of the different tags and inks used. These specific properties have guided the development of the relevant ontology concepts and properties.

Based on the review of the existing literature, we can state that the developed SmartTag ontology is the first effort to define a semantic model for SmartTags, including datamatrix, QR codes and NFC tags. Moreover, the model goes beyond capturing just static tag properties and their observations and includes constructs for describing tags printed using inks that undergo visible changes in response to changing environmental conditions.

An important aspect of the ink technologies is the encoding process, which is currently under development. The encoding of SmartTaG is an ongoing process and options how to ultimately perform encoding are being researched at the moment. and the will be used to further define the EncodingMechanism class of the ontology.

Future work on the semantic model includes defining rules in terms of the ontology concepts and properties to issue alerts for erroneous observations, for instance, for a SmartTag instance defined to have an irreversible lifecycle state, once a state change has been recorded, another one should not be possible. Other examples include associating defined values of threshold at which a state change should occur.

Updates to the SmartTag model to cater for the above will be reported in the D2.2 deliverable.

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17 TagItSmart D2.2 deliverable "Initial Enabler for FCs", due in April 2017.
Section 7 - References


