Robotic Shopping Assistance for Everyone: Dynamic Query Generation on a Semantic Digital Twin as a Basis for Autonomous Shopping Assistance

Extended Abstract

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ABSTRACT

While the Digital Twin technology can be used by robotic agents to autonomously digitise retail stores, the Semantic Web offers vast machine-understandable product information that can be utilised by both digital and robotic agents. We propose connecting shopping assistants to a semantic Digital Twin for a service-oriented shopping experience. The semantic Digital Twin connects product information from the Semantic Web to retail environment information created by an autonomous robot performing stocktaking. It can be used to retrieve relevant information for action execution by shopping assistants that dynamically generate queries to answer complex questions like "Where is toothpaste from (my preferred brand) containing natural ingredients?", thus making the contained knowledge actionable.

KEYWORDS

Digital Twin; Dynamic Query Generation; Semantic Web; Shopping Assistance; Robot Assistant

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1 INTRODUCTION

The next generation of robotic agents needs extensive knowledge about the actions they are to perform in relation to the environments they are operating in. While a robot in a museum will need knowledge about the objects, their creators and the epoch of creation, a shopping robot needs knowledge about available products and their ingredients in relation to customer needs. The development of shopping robots as autonomous shopping assistants for customers in retail stores or malls has been a research trend (Sec. 2).

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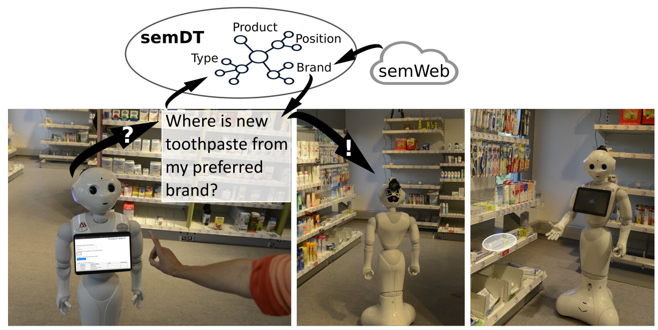

Figure 1: One shopping assistant enabled by this work.

While smart shopping carts or devices for self check-out can already be seen in retail stores, robotic agents are yet to be seen. This is due to various reasons. On the one hand, autonomous assistants need basic reliable knowledge about the environments they are operating in, such as knowing where articles are located. Additionally, they need to localise and safely navigate in fast changing environments with human traffic.

On the other hand, they need semantic knowledge to successfully perform actions. This work is based on a new approach to not manually encode semantic knowledge locally in a robot knowledge base but instead access semantic product information about objects a robotic agent perceives in a retail environment from a *Digital Twin* connected to the *Semantic Web*, thereby forming a semantic Digital Twin (semDT) [9, 13]. *Digital Twins* are exact virtual representations of real products or production environments [10], which we create for retail stores with robots that autonomously perform stocktaking as in [3]. *The Semantic Web* [4] (semWeb), an extension of the Web [17], offers structured content of Web pages in standardised formats, thereby representing entities, their properties and relations in a machine-understandable way. Thus, the semDT can be accessed and understood by robotic or software agents for service-oriented shopping assistance. Since the semWeb offers vast product information that can be linked for shopping applications, it can be used by these agents to autonomously answer complex questions like *"Where is the cheapest environmentally friendly detergent?"* or *"Where is new toothpaste from my preferred brand?"* as depicted in Figure 1.

We propose to dynamically generate queries that adhere to complex customer preferences to enable service robots as well as digital agents to autonomously use the semDT for action execution. Figure 1 shows the implementation of such a shopping assistant using a semDT that includes semWeb information to answer customer requests.

2 RELATED WORK

Shopping assistants navigating to a searched product have been a recent research trend(e.g. [11, 12, 15, 18].

Doering et al. [8] use a shopping robot to guide customers to a searched product in a home improvement store. For localisation of products they reuse a database designed for stocktaking of human employees. Unfortunately, they are only able to locate 83% of articles the store holds. In [7], the benefits of using a standardised map for localisation of products is highlighted. The Digital Twin belief state can be used to offer such a standardised map with exact real-time article positions [6, 13].

Existing shopping assistants offer limited services based on predefined queries to their customers. A query generation to search for a product using a set number and type of product features is benchmarked by Bizer [5]. In [16], a query generation based on keywords in natural language is introduced and extended to a query template in [16]. We reuse the idea of a query template and deploy it for shopping assistants.

3 DYNAMIC QUERY GENERATION

One of the benefits of using the proposed semDT is its platform-independency. A robotic agent running KnowRob [2] or a smartphone can easily connect to the semDT by accessing its REST API.

KnowRob can be queried in Prolog, a logic programming language. The Prolog implementation used in KnowRob also includes a SPARQL client library. Since SPARQL is the standard query language for graph databases [1], we use it to access the semDT graph database. The SPARQL queries used in this work return the global trade identification number (GTIN) of all products that match the consumer preferences and the shelves they are stored in. Example queries used by the agents can be found on the project website[1] using a grlc REST API [14].

With rich semantic object and position information being available in the semDT, a dynamic query generation that can handle different inputs is needed to autonomously answer complex user requests. We therefore developed an interface that generates queries based on user input on a website different agents can deploy as visualised in Fig. 3. The website consists of a tree view created out of ontology information to show product categories in descending order of abstraction with additional options to further narrow the search to customer preferences such as price or ingredients.

Based on the website input a query will be generated and sent to the semDT. The generation of queries uses a pre-defined template

[1]Project website: https://michaelakuempel.github.io/ProductKG/
Example SPARQL queries: http://grlc.io/api/michaelakuempel/ProductKG/SPARQLfiles/

```
{ select ?GTIN, ?shelf where {              }
{ ?product rdf:type category.               } base query
{ ?product gr:hasEAN_UCC-13 ?GTIN.          }
{ ?product gr:hasBrand brand.               } product brand
{ ?product loc:stored_in ?shelf.}           } base query
```

Figure 2: SPARQL query generated by the query template for the example request in Figure 1.

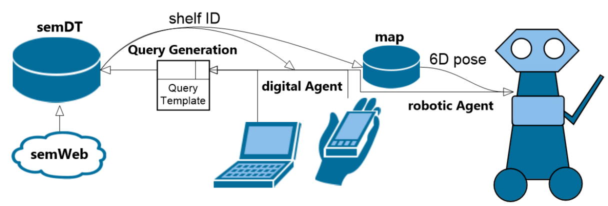

Figure 3: The Architecture of the Smartphone- and robot setup

which is shown for an example query in Figure 2. The template contains placeholders for every preference that can be entered on the website. Bold text highlights variables that are automatically filled by user input such as the product category and its brand. Since the website is constructed from ontology information, all preferences can be translated to variables in form of URIs of the ontology. The base query is always executed, while the placeholders are only integrated into the query if the variables are set.

Figure 3 shows the communication of different agents with the semDT. A digital agent in this case means a smartphone or a laptop, which can access the query generation via the website that can be included in any app. Service robots can easily display the website on their tablet. The website submits input parameters to the query generation so that a query such as in Figure 2 is constructed and sent to the semDT. The semDT returns the product GTIN and the shelf the searched product is stored in. For the smartphone this is sufficient for guiding a user to the shelf. The robot needs to translate the shelf ID to a 6D pose for navigation, which can easily be inferred from the map available within the semDT.

4 CONCLUSIONS

This work points out the benefits of dynamically generating queries on a semantic Digital Twin. The semDT with its connection of semantically enhanced environment information to object information from the semWeb can support robotic and digital agents in retrieving relevant information for autonomous action parametrisation. We extend this idea and implement a query template for dynamic query generation, enabling agents to autonomously pose complex questions and answer them by inferring action parameters to route customers to a searched product, which we successfully tested in a laboratory setup for various user requests. In future work we will demonstrate its use for shopping assistance in an experiment where customers pose complex queries like *"Where is new store brand juice located?"*. We will show how agents can easily use the proposed website and query template to route customers to searched products and will further investigate user acceptance.

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