FRAMEWORK OF MECHANICAL DESIGN KNOWLEDGE REPRESENTATIONS FOR AVOIDING PATENT INFRINGEMENT

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Abstract

Nowadays companies strive to stay competitive in the market by introducing innovative products and protecting their Intellectual Property by filing patents. However, with an increasing number of patents granted each year, designers face challenges in producing novel designs and patentable inventions such that early identification of potential patent infringement can help them to steer their design away from future litigation and towards a patentable novel solution. This paper presents a framework for representing mechanical design working principles contained in existing patents by developing the Function Analysis Diagram (FAD) and a domain-specific ontology. The developed FAD, named FAD+, provides design insights including device architecture, design features and the functional interactions amongst them. The ontology formulates patent knowledge representation and conceptualisation, which contributes to comparison of an emerging design to existing patents. Overall, the framework enables designers to obtain in-depth understanding of patents, increase their qualitative IP awareness and help them to identify potential patent infringement during the product development process.

Keywords: Functional modelling, Knowledge management, Computer Aided Design (CAD), Patent infringement, Ontologies

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1 INTRODUCTION

Intellectual Property (IP) disputes can be resource intensive and time consuming. A study conducted by Greenhalgh et al. (2010) indicated at least 24% of UK companies had experienced an IP dispute in the last five years. EPO (2006) highlighted an average litigation cost of £120K for UK small and medium companies and this figure can reach up to tenfold for large corporations. Therefore, it is understandable that engineering companies strive to avoid patent disputes to ensure successful promotion of new products. As a result, designers are encouraged to engage with relevant patents, increase their IP awareness during product development process rather than afterwards and thereby steering their design away from potential conflict. Patent infringement can then be avoided.

This paper presents a framework to represent mechanical design patents in structured formats such that a designer can obtain both rapid and in-depth understanding of the patents. Patents related to beverage can designs are used as examples for demonstration. The framework contributes to the establishment of a patent knowledge base which enables comparison of an emerging design to existing patents thereby enabling early identification of potential conflict prior art.

2 BACKGROUND

In 2015 world-wide patents granted had increased 37% compared to 2010 (WIPO, 2015). However the incremental increase has been dropping by nearly 50% each year (WIPO, 2015), indicating that companies and designers face challenges in producing novel designs and patentable inventions. The IP of these inventions is often protected by filing patents, which also contributes to a company's intangible assets, as securing patents is an effective way to maintain their competitiveness and sustain future development (Soo et al., 2006). Patent claims are central to a patent, in which the scope of protection and boundaries of the invention are defined (Koster, 2015). Patent infringement is clear when a single patent claim is trespassed (EPO, 2016), which can be understood as when all elements in a claim match the infringed design. Patent infringement is also defined as when a design has insubstantial difference with prior art and performs substantially in the same way, also known as the Doctrine of Equivalents or non-literal infringement.

Patents contain enormous technical and legal terminologies which make them difficult to understand especially for non-specialists (Kim et al., 2008). Despite this fact designers are encouraged to engage with patents in order to obtain insight of latest technologies and developmental tendencies in their domain of interest (Chen, 2009). Research conducted over the last decade concentrated on investigating patent similarities through automated patent analysis and mapping. For example, Cascini and Zini (2008) measured patent similarities employing function tree representing invention components, and Li et al.(2014) proposed TRIZ-led patent mapping to investigate patent conflicts using TRIZ 39 parameters. It appears that more could be done to help designers to understand patents in depth, increase their awareness of the prior art during a product design process and thereby avoid potential conflict with their emerging design. Patent novelty and inventive step that together define the patentability of an invention, which may be easier for designers to understand. Novelty describes the degree of originality in the field of application; and inventive step, describes whether the design is an adequate step forward from the current state of the technology. However, novelty and inventive step are still legal definitions and therefore in this paper we will explore novel 'working principles' (Pahl and Beitz, 2006) of patents as an indicator of potential novelty and inventive step. Novel working principles can be seen as directly linked to the innovative solutions described by a patent by having novel technical features and/or novel functional interrelationships.

With increasing complexity of engineering products, novel working principles of mechanical designs are often reliant on detailed geometric features and the way they interact. Geometric feature here refers to a broader sense than geometrical product specification defined in the international standard (ISO 5459:2011, 2011). It describes technical features that relate to device functions and may also be used to describe a product sub-system or component such as motors or shafts, or detailed geometry features of devices such as holes, flanges and surfaces. We investigate patent novel working principles through in-depth functional analysis, and explore how these design solutions are achieved by interacting geometric features. As a systematic approach to technical problem solving (Pahl and Beitz, 2006), functional analysis enables designers to learn and develop products by describing, decomposing and relating product functions to systems in order to achieve end product success (Morris and Breidenthal, 2011).

Functional representation is familiar to designers as a tool to perform systematic functional analysis that has been developed over decades and exists in various formalisms. Functional Analysis Diagram (FAD) (Aurisicchio et al., 2013), a form-dependent functional modelling approach that expresses functional interactions between product components in natural languages, has been broadly applied in both academia and industry to enable in-depth understanding of a product, reveal critical points in design and provide opportunity for further improvement (For example see Aurisicchio et al., 2013; Lee, Jiang and Childs, 2013; Lee, Jiang, Childs, et al., 2013; Michalakoudis et al., 2014). In this paper an extension of FAD, namely FAD+, which focus on functional reasoning of patents was developed to represent detailed geometric features and functional interactions amongst them. A common design vocabulary called Reconciled Functional Basis for design (RFB) (Hirtz et al., 2002) was adapted to describe the functional interactions enabling a standardised format of functional representation. Rigorous validation of the RFB vocabulary has contributed to its proven value in engineering design (Ahmed and Wallace, 2003) and its ability to adapt to represent functions in specific domains.

Patents published by different patentees normally use various terms in describing designs which may create difficulty for other designers to understand. In fact some patentees intentionally use ambiguous terms to confuse their competitors in order to broaden their patent scope as much as possible. In the context of functional analysis, terms used when describing a design by different designers and organisations are usually diverse too. Sometimes different terms are used in describing similar designs that carry similar working principles. For instance, ‘aperture’ and ‘hole’ in two designs can describe the same type of opening that offers the same function. As a consequence, an ontology that semantically summarises patent terms using standardised entities is appreciated. Ontology is essentially a shared knowledge base for vocabulary creation and data sharing (W3C, 2015), composed of a conceptualisation of domains. It performs as a repository of interlinked entities, describing both their abstract and concrete meanings (Kotis and Vouros, 2006; Nicola and Missikoff, 2016). Its value in terms of enabling knowledge sharing and standard design language development has already been recognised (For example, see Ahmed, Kim, and Wallace 2007). An ontology built around a specific application type of product is defined as domain-specific ontology in which relevant patent knowledge can be populated into the ontology to create interlinked data. Patent knowledge needs to be organised using appropriate structures for the purpose of ontology development. In the field of product development, Gero (1990) introduced Function-Behaviour-Structure (FBS) theory which describes classification of design knowledge. Function to Structure for example, justifies the mapping from product function to system structure, explaining how functions are achieve through interrelationship between technical features. Despite the FBS framework being a relatively old concept, developments have continued with for instance, Cascini et al. (2013) adapting the FBS framework to represent product needs and requirements in the early stages of design. Russo and Spreafico (2015) used FBS theory in their research to classify the 40 inventive principles of TRIZ. As a result FBS theory is adapted in this paper to classify patent knowledge into Function, Behaviour and Structure and thereby demonstrating patent working principles. In conclusion, the need for systematic mechanical design patent functional representation, knowledge structuring and a standardised vocabulary for patent term conceptualisation are identified. In the next section FAD+ is introduced as a functional representation for mechanical design patents.

3 FAD+ AS PATENT FUNCTIONAL REPRESENTATION

FAD+ is developed as an approach for representing invention working principles concentrating on device feature ownership, device geometric features plus functional interactions amongst them and device functions with associated structures. Information represented in FAD+ is split into three tiers respectively and they enable a designer to investigate a patent from different perspectives. Each tier of FAD+ is individually represented and can be revealed separately upon designer’s request. FAD+ notation is presented in Figure 1. The software used to produce FAD+ was designVUE (Imperial College London, 2016), a branch of VUE (Visual Understanding Environment) originally developed by Tufts University.

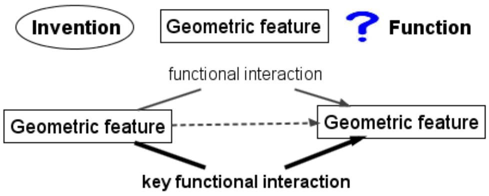


Figure 1. FAD+ notation

Information required to produce a FAD+ can be gathered from textual information contained within patent claims and summary. For example, nouns describing the invention can be classified as geometric features and verbs can be classified as functional interactions between geometric features. Key functional interactions are labelled as key if they are gathered from patent independent claims in which patent novel working principles must be explicitly stated. In other words, working principles revealed in patent independent claims can be seen as an indicator of potential novelty and inventive step. This offers a systematic and potentially automated approach to develop a FAD+. **Invention** indicates the invention name. **Geometric feature** is expressed using patent terms. Patent terms refer to exact phrases used in the patent document when describing a design. The dashed line between geometric features provides an indication of feature ownership. **Function** refers to the effect of interacting geometric features which can normally be identified from patent summary and the end of each patent claim. It can be seen as the designer's intention in creating those geometric features. It describes a higher level functional requirement prior to system structure consideration and is normally described using a Verb and Noun couplet that refers to RFB. For example, 'transmit Torque', 'create Opening', where the Noun starts with a capital letter for easy recognition. **Functional interaction and key functional interaction** are expressed using RFB vocabulary. Functional interactions also include spatial and dimensional relationships between geometric features to describe physical arrangement of geometric features. A FAD+ example for a beverage can stacking clip device (US 20150210428) is used for demonstration, where Figure 2 shows an image from a design embodiment of the stacking clip that enables two cans to be connected for improved stacking.

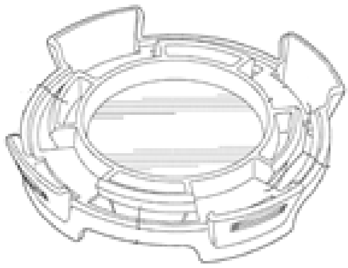


Figure 2. Beverage can stacking clip patent image (US 20150210428)

3.1 FAD+ represents device feature ownership (tier 1)

FAD+ in this tier focuses on providing insight on the invention feature ownership, for example, see Figure 3. It aims to help the designer obtain an overall understanding of the invention architecture.

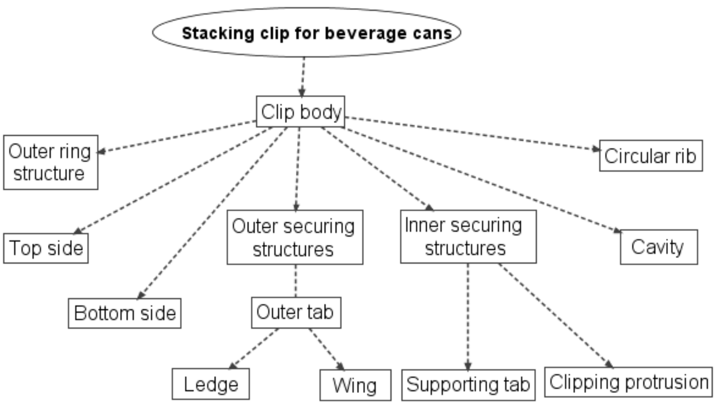


Figure 3. FAD+ tier 1 indicating device architecture

From Figure 3 it can be easily understood that the patent introduced a stacking clip device, and it contains a 'Clip body' which comprises several geometric features including 'Outer ring structure', 'Top side' and 'Circular rib'. More detailed geometric features are also indicated, e.g. 'Ledge' and 'Wing'.

3.2 FAD+ represents geometric features and functional interactions (tier 2)

The next tier of FAD+ concentrates on indicating all invention geometric features stated in patent claims and functional interactions amongst them. Figure 4 demonstrates FAD+ for the stacking clip. Key functional interactions provide insight on invention novel working principles. For example, one novel working principle of this patent is that the Ledge was used to capture and disjoin the Outer lip of the can in order to attach and separate two cans.

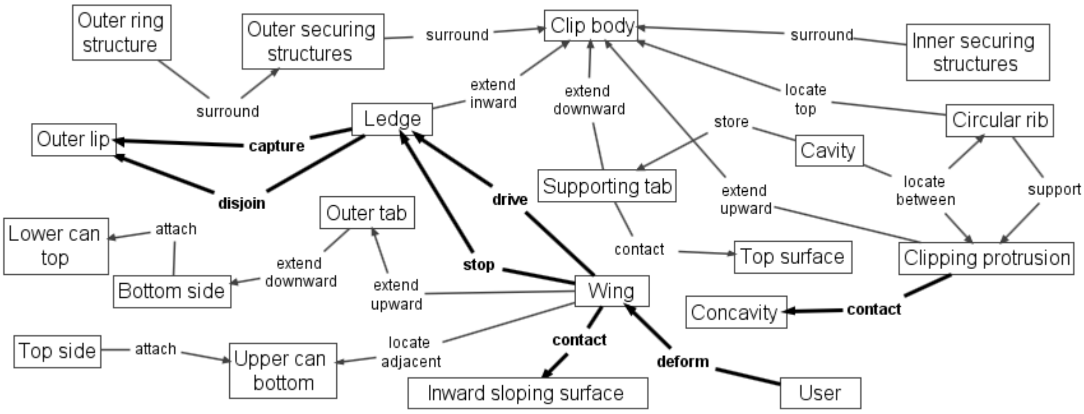


Figure 4. FAD+ tier 2 indicating patent geometric features and F-GI

3.3 FAD+ represents Function and Structure (tier 3)

In this tier, Functions carried out by a device are highlighted and presented individually with the relevant Structure, i.e. geometric features and their functional interactions. Example functions 'secure Can' and 'separate Can' for the stacking clip patent are demonstrated in Figure 5.

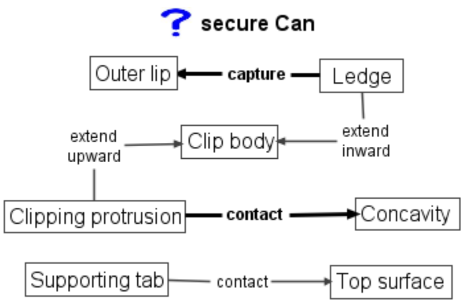


Figure 5. FAD+ 3rd tier indicating Function and Structure

From Figure 5 example Function offered by the stacking clip and their corresponding Structure can be seen. For example, in order to separate two cans, the 'User' will need to deform the 'Wing', so the 'Wing' can drive the 'Ledge' to 'disjoin' the 'Outer lip' of the can.

In conclusion FAD+ offers insights on different aspects of a patented design, aiming to help designers obtain in-depth understanding of the working principles without the need for reading the patent document. Graphical representation of patent functional models also contributes to the value of the patent compared to text description alone. Patent knowledge represented in FAD+ can be formulated and computerised to enable comparison between an emerging design and existing patents. This can be achieved by developing a domain-specific ontology that transforms FAD+ into ontological format and enables patent terms to be semantically abstracted into generalised entities.

4 DOMAIN-SPECIFIC ONTOLOGY DEVELOPMENT

Development of the domain-specific ontology was accomplished in two stages: construction of the patent ontology structure followed by development of domain focused ontology. This enables the domain-specific ontology to be tailored to different fields of application.

4.1 Patent ontology structure

For this stage the ontology structure of a patent was developed and used to represent its knowledge. It can be understood as a structure outlining patent knowledge types and their relationships. Referring to RFB, an Action and Object couplet was used to describe function, e.g. ‘transmit torque’, ‘create opening’. An Object and Attribute couplet was adopted to describe behaviour, e.g. ‘transmission ratio’, ‘force quantity’. Geometric features are expressed using patent terms. Functional interactions are expressed using an Action phrase, e.g. ‘attach’, ‘separate’.
From the perspective of identifying commonality in working principle, similarity in behaviour is fairly irrelevant due to its minor impact. For example, having a design functioning identically but with a larger transmission ratio is still counted as conflict using our method therefore behaviour is not our primary focus here but we envisage that offering behaviour analysis when conducting comparison may stimulate further improvement of the emerging design.
Triple-store concept (Rusher, 2003) has been broadly applied for data storage and retrieval in semantic databases in the form of triplet, which is composed of subject–predicate–subject. This suits the way FAD+ represent an invention using combinations of geometric feature-functional interaction-geometric features. For example, user lifts tab; gear transmits torque. Therefore it was adopted for developing the ontological format of patent knowledge representation. . Building on the FBS framework and triple-store concept, the patent ontology structure for mechanical design is presented in Figure 6. Each mechanical design contains functions and each function is defined by an action and an object. Each function also has triplets and each triplet is composed of ‘FunctionalElement1’, ‘TripletAction’, i.e. functional interaction and ‘FunctionalElement2’. This can be understood as a function is achieved by the effect of combination of interacting geometric features. Similarly, each function has behaviours defined by an object and attribute. Each behaviour relates geometric features ‘BehaviourElement1’, ‘BehaviourElement2’, etc. Both ‘FunctionalElement’ and ‘BehaviouralElement’ are represented using patent terms to provide easy traceability.
Patent term conceptualisation process can be identified from the ontology structure in Figure 6. For example, ‘FunctionalElement1’, i.e. patent term is connected to ‘Element1’ via relation ‘isElement’, ‘Element1’ isRelatedTo ‘Object’ which is a generalised design entity. This patent ontology structure was formulated and exported using Protégé (version 5.0.0), an ontology building software developed by Stanford University.

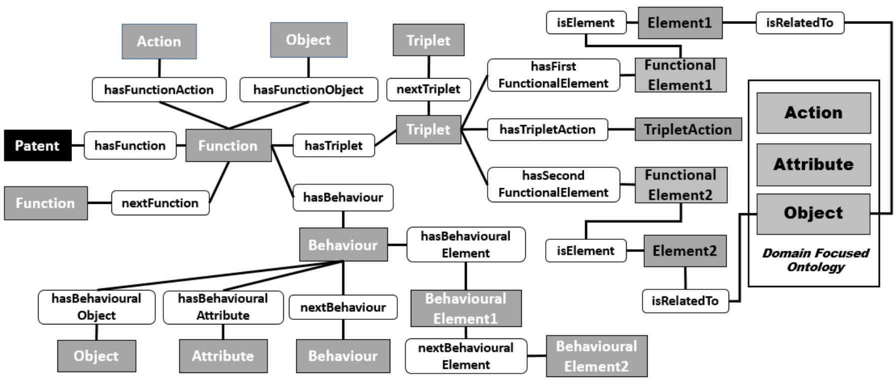


Figure 6. Patent ontology structure for mechanical design. (Connection between Behavioural Element and Object is not shown)

4.2 Domain focused ontology

In this stage ontology terms, i.e. generalised design entities, were collected and recorded and organised and for demonstration purposes applied to beverage can designs. Development of the domain focused ontology employed UPON Lite ontology engineering approach (Nicola and Missikoff, 2016).

Conventional ontology engineering process normally require significant input from domain experts in the form of interviews and questionnaires. This method provides a rapid and robust approach for developing a domain-specific ontology by sharing fundamental data among ontology engineers and domain experts in form of spreadsheets enabling convenient modification and improvement. The process developed contains three phases: Taxonomy, Glossary and Ontology. Data created in these phases were iteratively validated by domain experts via secured shared cloud drive.

In Taxonomy design entities were documented and structured in a hierarchical manner. Initial data was gathered by analysing sample beverage can design patents identified by conventional patent search. Taxonomy was classified into action, object and attribute referring to the patent ontology structure. A range of common physical effects and material characteristics in mechanical design were assigned to attribute, and were hierarchically organised to enable semantic association. For some mechanical designs such as beverage cans there are circumstances that spatial and dimensional interactions between design features are important in achieving a function therefore they are classified as action too. Partial lists of the data gathered are illustrated in Figure 7. In the Glossary phase synonyms for entities defined in Taxonomy were explored and documented. This phase enhances the capability of the ontology to recognise patent terms used by different people and organisations and ensure that the semantic meanings are captured and related to the entities defined in Taxonomy. Relationships between ontology entities defined in Taxonomy were specified in the Ontology phase using isRelatedTo, which indicates a general association between two entities. For example, 'disjoin' isRelatedTo 'separate'.

Top concept	1st level	2nd level
branch	separate	disjoin
		extract
		isolate
	break	
	eject	emit
	dispense	pour
	remove	eliminate
	distribute	
channel	guide	
	transport	carry
		advance
		move

Action

Top concept	1st level	2nd level
User	Hand	Finger
	Eye	
	Mouth	Tongue
		Lip
		Teeth
Material	Liquid	Beverage
		Water
	Solid	Powder
		Metal
		Plastic
		Crystals

Object

Top concept	1st level
Rate	
Ratio	
Quantity	
Distribution	Arrangement
	Location
Loss	
Quality	Accuracy
	Reliablity
Collection	Collection rate
	Collection quantity
	Collection ratio

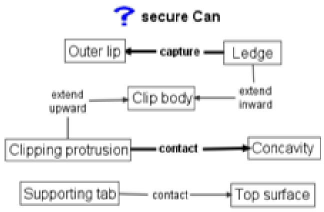
Attribute

Figure 7. Partial list of domain focused ontology initial data for beverage can design

5 PATENT KNOWLEDGE REPRESENTATION

Having developed FAD+ (section 3) and domain-specific ontology (section 4), patent graphical representation can be transformed into an ontological format, recorded in a spreadsheet first for easy validation. The validated data can be then transcribed in JSON (JavaScript Object Notation format) in which conceptualisation of patent terms is conducted at the same time referring to the ontology. JSON format of patent knowledge representation facilitates the data population and enables a RDF (Resource Description Framework) data model to be constructed. The model can be seen as a semantic knowledge based enabling designer to send semantic queries and retrieve relevant patent data.

Figure 8 shows the transformation of patent knowledge representations for the stacking clip patent from FAD+ to JSON using the example function ‘secure Can’. Patent term conceptualisation was also demonstrated in the figure. For example, ‘Supporting tab’ was standardised to ‘Rib’, ‘Clipping protrusion’ was conceptualised to ‘Barb’. Patent term conceptualisation with designer's input ensures the accuracy of data association and can be refined by domain experts. It can be easily seen that five pairs of interacting geometric features indicated in FAD+ correspond to five triplets in both the spreadsheet and JSON.



Function	Behaviour	Structure		
action + Object	Object + Attribute	FunctionalElement#1	Triplet TripletAction	FunctionalElement#2
align Can	Position accuracy	Supporting tab	contact	Top surface
		Clipping protrusion	contact	Concavity
		Wing	contact	Inward sloping surface
		Bottom side	attach	Lower can top
		Top side	attach	Upper can bottom


```
"relations": {
        "Supporting tab": "Rib",
        "Clipping protrusion": "Barb",
        "Wing": "Wing",
        "Bottom side": "Can clip",
        "Top side": "Can clip",
        "Ledge": "Barb",
        "User": "User",
        "Cavity": "Cavity",
        "Top surface": "Surface",
        "Concavity": "Cavity",
        "Inward sloping surface": "Surface",
        "Lower can top": "Can end",
        "Upper can bottom": "Can bottom",
        "Outer lip": "Edge",
        "Clip body": "Can clip",
        "Circular rib": "Rib"
},
```

```
"action": "secure",
"object": "Can",
"hasStructure": [{
        "hasElement1": "Ledge",
        "hasF-GI": "capture",
        "hasElement2": "Outer lip"
}, {
        "hasElement1": "Ledge",
        "hasF-GI": "extendinward",
        "hasElement2": "Clip body"
}, {
        "hasElement1": "Supporting tab",
        "hasF-GI": "contact",
        "hasElement2": "Top surface"
}, {
        "hasElement1": "Clipping protrusion",
        "hasF-GI": "contact",
        "hasElement2": "Concavity"
}, {
        "hasElement1": "Clipping protrusion",
        "hasF-GI": "extendupward",
        "hasElement2": "Clip body"
}],
"hasBehaviours": [{
        "object": "Connection",
        "attribute": "Reliablity",
        "hasElements": ["Ledge", "Outer lip", "Clipping protrusion", "Concavity"]
```


Figure 8. Conversion process of patent knowledge representation

6 DISCUSSION

As a further development of FAD, FAD+ focuses on functional reasoning of mechanical design patents in which their novel working principle may be reliant on detailed geometric features and the way they interact. FAD+ also provides the means of representing patent knowledge including device ownership, device functions, key geometric features and functional interactions. By examining FAD+ designers will be able to obtain understanding of relevant prior art, increase their qualitative IP awareness and thereby avoid potential conflict with their emerging design. Current FAD+ development has been accomplished by the authors through patent document examination to ensure accurate knowledge extraction. At this point we focus on the effectiveness of the FAD+ framework rather than automation of data input but we envisage that employment of natural language processing (NLP) tools can considerably shorten the production time. Bear in mind that the main objective of FAD+ is to offer the designer insights into patent novel working principles, legitimate novelty and inventive step still require patent professionals to determine.

Development of a domain-specific ontology enables patent term conceptualisation and data association. It can be seen as a shared knowledge base that uses standardised entities in describing mechanical designs and inventions. Terms used in describing functional interaction between design features are obtained from the domain-specific ontology. Beverage can patents were used for demonstration purposes and therefore initial data input was generated from relevant patents gathered by conventional search. This involves the RFB vocabulary development for the purpose of this study. Employment of domain-specific ontology and systematic development process of FAD+ ensures the consistency of FAD+ production. FAD+ produced from patent independent claims generally takes around 15 mins which is considerably shorter than reading a patent document. With a range of patent knowledge represented using the ontological format derived from FAD+ a semantic knowledge base can be built enabling comparisons between the emerging design and existing prior art. This can be achieved by retrieving matching triplets contained within both emerging design and prior art in the form of semantic queries, i.e. similar working principles suggest conflict. Information contained within a query can include device functions, geometric features, functional interactions or any combinations of them. In terms of knowledge base validation and refinement an iterative human-centred refinement approach can be employed. We invite designers to utilise the knowledge base for evaluation and feedback. Inaccurate and missing data association can be removed or added to the knowledge base by the designer.

Identification of similar working principles between emerging design and patents designs provides a tangible opportunity to identify potential conflict prior art. It is worth noticing that we are not trying to replicate a legal tool that replaces patent attorneys and makes legal judgements. Instead it acts as an assistant tool that helps designers obtain rapid yet in-depth understanding of patent working principles and to increase their qualitative IP awareness during the product development process rather than afterwards. Different types of result such as quantitative comparison results can also enable designers to visualise the comparison and make adjustments accordingly.

This framework of patent knowledge representations contributes to a computer assistant tool being developed, namely Design Assistant for Semantic Comparison of Intellectual Property (DASCIP), whose overall structure is shown in Figure 9. Patent Functional Models are essentially FAD+ representing patent working principles. Text Annotated Patent Images are a concise summary of a patent working principle using annotated text boxes to help designers initially understand the design more easily. Together with the Domain-specific Semantic Knowledge Base these three components contribute to a greater knowledge base, comprising different format patent knowledge representations. Information within the knowledge base will be accessible through a User Interface integrated in a CAD system. The UI is mainly responsible for end designer engagement, allowing them to generate emerging design working principle. The UI also acts as a visualisation tool that displays real-time quantitative comparison results. Another important function of the UI is that it enables iterative refinement of the knowledge base. The main reason we chose to implement DASCIP at the CAD modelling stage is that usually this is where conceptual designs are developed into detail designs. In this stage design solutions are embodied with tangible product structures and geometric features. DASCIP will identify potential conflict by investigating how function is achieved by detailed geometric features and the way they interact for both the emerging design and relevant patents. We envisage that applying DASCIP in mechanical product development will help designers to increase their qualitative awareness of IP and identify potential conflict prior art during the design process and thereby avoid risk of potential infringement and shorten the product development cycle.

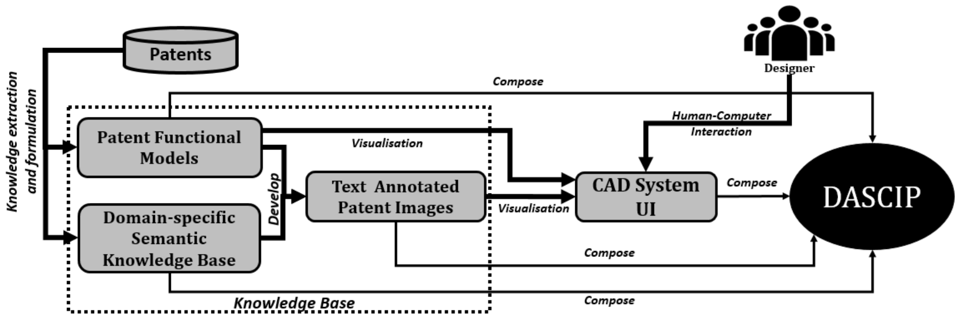


Figure 9. DASCIP structure overview

7 CONCLUSION

Designers are encouraged to engage more with patents during the product development process as a result of the increasing complexity of mechanical designs and volume of granted patents. In this paper various formats of mechanical design patent knowledge representations with the purpose of increasing designer's IP awareness are presented. FAD+ offers patent graphical functional representation incorporating device ownership, key geometric features and functional interactions, which provides insight into patent novel working principles. A domain-specific ontology provides standardised vocabulary enabling patent term conceptualisation and patent knowledge formulation. Patent knowledge represented in triple-store format contributes to facilitated knowledge base population and design comparison. Similar working principles identified between an emerging design and existing patents act as an indicator of potential conflict. FAD+ and the ontology will contribute to a computer assistant tool being developed, which is envisaged to be integrated into a CAD system, allowing designers to perform real-time comparisons and enable them to visualise the risk of potential prior conflict. Next steps include the development of the CAD system User Interface and refinement of the domain-specific ontology.

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