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ABSTRACT

Affordance based design is developed since the beginning of 21st century. Affordances being revealed properties of a system in a context, they may be much diverse and unexpected. Consequently, it is an utopia to think of enumerating all the existing precise affordances in advance. Presently, identifying affordances along a design or redesign process is based on experiments and focus groups, which are time and resource consuming. Although automatic identification strategies have been proposed, the lack of affordance database along with clear categorization technique makes it unpracticable and non-repeatable today. In this paper, the theoretical basis and technical basis of identifying affordances from online reviews are discussed. A framework of affordance identification is proposed by capturing constitutive affordance elements with natural language processing algorithms. Meanwhile, a case study of 303 review sentences of Kindle Paperwhite from Amazon.com is conducted with 1 expert in affordance based design and 6 participants. The result shows that the proposed framework is effective in affordance identification. It provides basis for automating the identification process in the future.

1 INTRODUCTION

First put forward by perceptual psychologist Gibson (1979), the concept of affordance has been widely accepted in various fields in recent years, such as artificial intelligence and human childhood development. At the beginning of 21st century, Maier and Fadel (2001) systematically introduced the affordances into design engineering. They define the affordances of artefact as "relationships between two subsystems in which potential behaviours can occur that would not be possible with either subsystem in isolation". The affordance based design theory is then developed to provide designers a complementary systematic process to design industrial products (Maier and Fadel, 2003).

In the affordance based design process, affordance identification is an important step (Maier and Fadel, 2005). It helps designers express the customers' expectations and choose or design an appropriate artefact to fulfil these expectations as well as useful emerging roles of this artefact in its context. Various affordance identification methods can be found in prior researches of affordance based design. However, since they are mainly based on interviews and focus groups, the present identification methods are time and resources consuming. Meanwhile, the identification results through interviews strongly depend on participants' knowledge and experiences (Chou and Shu, 2014). Although automated identification methods are proposed (Maier and Fadel, 2007), the lack of affordance database makes them unrealizable in practice.

To tackle these issues, online customer reviews of artefacts drew our attention. Nowadays, almost all the online markets open opportunity for customers to leave their product reviews on the webpage. Therefore, the volume of online reviews is large. Meanwhile, online reviews are easy to process by existing automated scrapping tools followed by text mining techniques.

However, do affordances really exist in online reviews? Is it thinkable to detect, interpret and encode in a unique manner a set of affordances from the analysis of a customer review made of several sentences? Recent research shows that customers share their product reviews on the webpage in search for the sense of helping and belongingness (Cai et Chau, 2015). Whereas to make their reviews useful and persuasive, reviewers tend to give examples of their own usage of product, in other words, their interactions with the product. Coincidentally, affordances also describe interactions. They can be understood as the action possibilities of a user interacting with a designed object (Gero and Kannengiesser, 2012). Thus, the above observation provides the theoretical basis for affordance identification from online reviews.

In consequence, how to extract affordances from online reviews now becomes the key question. On the one hand, since the customer reviews are freely written without any imposed format, it is inherently difficult to process (Wang and Dong, 2008). On the other hand, reading and analysing manually such a large amount of online reviews is time and resource consuming.

In this paper, based on the ontology of affordance based design proposed by Mata and Fadel (2015) and natural language processing algorithms, we propose a framework to identify affordances from online reviews by capturing constitutive affordance elements. Afterwards, a case study is conducted to assess the effectiveness of the proposed framework in terms of correctly identifying affordances from online customer reviews.
The paper is organized as follows: Section 2 reviews the related work on affordance based design, affordance identification and natural language processing. Section 3 introduces the constitutive elements of affordance. Section 4 presents means to capture each element and discover structured affordances. Section 5 gives a case study with 303 customer reviews of Kindle Paperwhite from Amazon.com. Section 6 discusses the results. Finally, section 7 concludes the research with perspectives.

2 RELATED WORK

2.1 Affordance based design

The concept of affordance was firstly put forward by perceptual psychologist Gibson (1979). Gibson coined the term "affordance" as "what it offers the animal, what it provides or furnishes, either for good or ill". Later, the psychologist Norman (1988) took Gibson's theory of affordance and extended it into the design of everyday things. He simply gave some guidelines as to what certain objects should afford and should not afford. At the beginning of 21st century, Maier and Fadel (2001) argued that the affordances should be the fundamental concept in design engineering.
Based on this observation, affordance based design process is developed by Maier and Fadel (2003). The process illustrates how to design a product that provides required affordances. Discussions and comparisons are then made between function based design and affordance based design. Research shows that affordance based design is more advantageous in explaining the evolution of artefacts, designing complex systems and redesigning existing products (Maier and Fadel, 2009). However, the trouble is that the spectrum of affordances is much wide, not to say infinite. During the whole design process, designers can consider the affordances of a device as the set of all potential human behaviours that the device might allow. Therefore, it is not easy for designers to identify all the affordances of the product at early design phase (Brown and Blessing, 2005).

2.2 Affordance identification

Various methods are offered to designers in prior researches to identify affordances. Globally, three kinds of different strategies lie in these methods.
The first strategy is pre-determination, in which a generic affordance structure is needed. Designers are recommended to use the generic structure as a checklist to make sure all aspects of affordance have been considered. One of the generic affordance structures is proposed by Maier and Fadel (2001). It categorizes the affordances mainly by product's life cycle stages, such as "afford human use", "afford maintenance", "afford retirement", together with "afford desired use" and "afford undesired use". However, some categorisations are imprecisely defined. For example, the difference between "human use" and "desired use" is unclear. In recent research, Cormier et al. (2014) propose another generic affordance structure (see Figure 1), in which the range of affordances is enlarged, leading to more precise affordance categories.

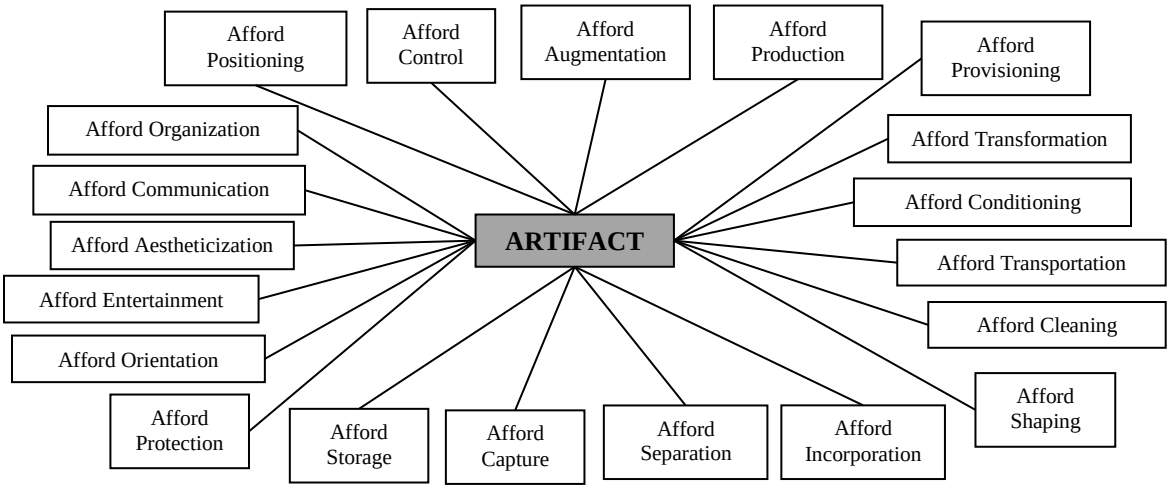


Figure 1 Generic affordance structure (Cormier et al., 2014)

However, the limitation of this strategy is that the generic structure can only provide affordances that all the products possess or should possess, whereas specific affordances cannot be deduced.

The second strategy consists in experimentation. It requires an existing artefact to be experimented upon. The artefact is given to participants to manipulate, then affordances are identified through observations during the experiment or interviews after it. In a comparative study of function based design and affordance based design, the affordances of a computer docking station are identified through direct experimentation (Maier and Fadel, 2005). Recently, Shu et al. (2015) proposed a method based on direct experiment to identify novel affordances. The novel affordance is defined as affordances which exist on the artefact but was previously unknown to the designers or users. In their research, they found that an absence of material or features of an artefact affects the utility of products, and absences are thus applied to identify the affordances.

The strategy of experimentation is widely used in the prior research of affordance based design. However, the first problem of this method lies on the availability of physical prototype. More specifically, in the early design phase, physical prototypes are often not available for direct experiment. Whereas at the end of the design process, when physical prototypes are available, it will be costly to add unpredicted affordances or delete undesired affordances. Virtual prototypes seem to provide a solution, while the lack of physical interaction still limits the detection of affordance. The second problem is that the identification result depends on the knowledge and experiences of participants (Chou and Shu, 2014). Consequently, the quantity of samples should be large enough to ensure the pertinence of identification results. The whole process requires thus more time and resources.

The third strategy is automated identification. Computer science plays a key role in it. Maier and Fadel (2007) propose that using modern technology, maps between existing artefacts' properties (shape, material, etc.) and affordances can be stored in a database. Thus, expert knowledge about the affordances can be captured from this database and integrated into a computer assisted design environment. Unfortunately, the construction of an affordance database is a huge work, we do not see such a database by now. Recently, Chou and Shu (2014) proposed a heuristic method to identify affordances from product reviews. In this method, customer review sentences are vectorised by their language features such as coordinating conjunctions, proper nouns and adverbs. Then a k-means clustering is processed to decompose the customer reviews into “noise” and “informative sentences”. Finally, they found that novel affordances can be targeted from informative sentences with the help of cue phrases like "as opposite to" and "can actually", because unexpected usage are more probably to appear together with these cue phrases in online reviews. However, designers still have to read the customer review sentences, for the description of affordance is not automatically constructed. Also, in their case study, the highest precision 32% is reached by using "as opposite to" as cue phrase. This precision is relatively low, which means that affordances can be identified in only 32% of review sentences that contain “as opposite to”.

As summarized above, to the best of our knowledge, all the identification methods have limitations. To be able to identify affordances within limited time and resource condition, new methods must still be developed. Inspired by Chou and Shu (2014), we believe that online reviews can overcome the

deficiencies of present identification methods. In fact, with mature technologies of scrapping tools and natural language processing algorithms, extracting information from online reviews is much cheaper and faster than by physical experiments (Popescu and Etzioni, 2007). Meanwhile, the reviews come from real interactions between customers and products, ensuring the accuracy of identification results. Also, the variety of reviewers' experiences and usage conditions provide rich contexts of specific affordances related to a given product.

2.3 Natural language processing

Natural language processing is widely used in the analysis of online reviews to extract useful information. POS-tagging (Part-Of-Speech tagging) algorithms is often used to pre-process the review sentences. Every word in the sentences is labelled with its lexical categories, such as subject, predicate, object, adverb, etc. Existing POS-tagging algorithms are mostly based on probabilistic model. The accuracy can prominently reach as high as 96% (Schmid, 2013).

In online review analysis, feature extraction algorithms allow us to extract features of product from online reviews. Sentiment analysis algorithms assess the satisfaction of reviewers by giving a score to each phrase. Raghupathi et al. (2015) proposed a heuristic algorithm to evaluate the global sentiment of a review sentence. In this work, the basic database is a *Dictionary of Affect Language* (DAL) which associates an average score of pleasantness for human mind for each of the 200,000 English words (Whissel, 1989). The text is analysed word by word for globally rating sentiment. It appears that the data structure of a sentiment is here extremely basic, compared to what can be an affordance. Zhang et al. (2016) also proposed an unsupervised machine learning algorithm to jointly identify product features and sentiments words at the same time. The effectiveness of the algorithms is proved in each study. The above literatures provide us the technical basis for identifying affordances from online reviews. The authors believe that the notion of affordance being more sophisticated than the one of sentiment, expectations are higher for the process of designing.

3 CONSTITUTIVE AFFORDANCE ELEMENTS

An affordance ontology is already proposed by Mata and Fadel (2015) for the designers to formalize affordance based design knowledge. In this ontology, the affordance class contains two objects and four properties (Figure 2). The first object is denoted as “primary entity”. It defines the artefact that provide the affordance. The second object is denoted as “secondary entity”. It indicates the executor of the action that the product might allow, which is either a human(user), an artefact, or an environmental material. The four properties are “affordance description”, “polarity”, “priority” and “quality”. Affordance description defines how affordances are represented in words. As shown in Table 1, three affordance descriptions already exist in previous research (Hu and Fadel, 2012). Polarity refers to the direction of influence of the affordance. For example, the cutting-ability of a knife is a negative affordance because it can hurt the user. Priority informs how important the affordance is compared with the other affordances of the product. Finally, quality defines how well an affordance is achieved. For example, a chair and a briefcase both have the affordance of sitting-ability. It is expected that the sitting-ability of a chair has a higher quality than that of the briefcase.

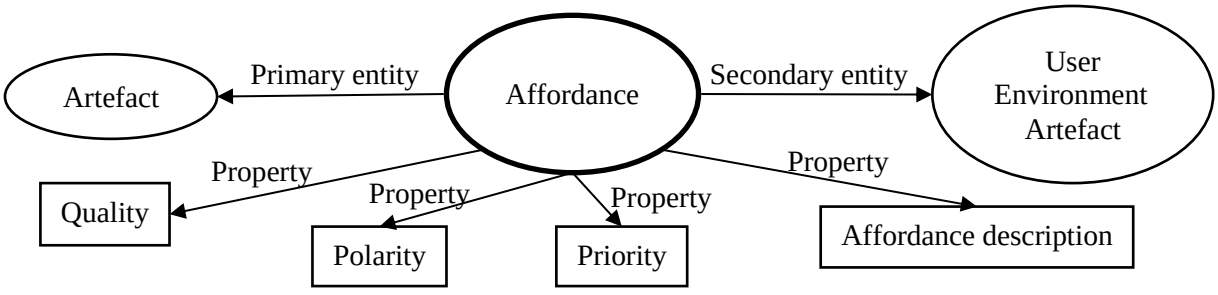


Figure 2 Five constitutive elements of affordance in online reviews, inspired by affordance based design ontology proposed by Mata and Fadel (2015)

Table 1 Existing affordance description formats (Hu and Fadel, 2012)

Format	Alternative format	Example

Verb + -ability		Grab-ability, weist-ability
Verb + noun + -ability	Noun + verb + -ability	Lift handle-ability, rotate gear-ability
Transitive verb + noun	Intransitive verb	Collect water, lubricate part

An affordance instance is fully defined when these objects and properties are specified. However, some changes are made when identifying affordances from online reviews. First, as the priority of affordances is subjectively defined by designers based on the requirement of project, it is not to be identified from online reviews. Second, the usage condition or usage purpose are included in affordance description, if exist, because it further defines the environment of interaction. Thus, based on the ontology, five elements are captured from online reviews to construct an affordance.

- Affordance description
- Artefact (primary entity)
- User/Artefact/Environment (secondary entity)
- Quality
- Polarity

4 AFFORDANCE IDENTIFICATION FRAMEWORK

In this section, an affordance identification framework by natural language processing is proposed based on the constitutive elements (Section 3). Figure 3 shows a synoptic of the framework.

4.1 Pre-processing online customer reviews

The unguided review environment leads to significant amounts of irrelevant information when seeking useful affordance-related insights. It is worthwhile to develop methods to extract potentially useful information. Chou and Shu (2014) provide an effective algorithm to eliminate uninformative review sentences, which contain only buying information, personal preference, product comparisons, etc. For example, in the review sentence "I still recommend that you buy a Kindle without special offers", the reviewer describes a personal preference. No affordance can be tracked from this uninformative sentence.

The algorithm consists of three steps. First, the online reviews are vectorised by language features, such as frequency of adverbs, purchase words, proper nouns, etc. Second, a k-mean clustering is processed to generate two clusters that decompose the text meaningfully. Third, by POS-tagging algorithms, the words in informative review sentences are labelled with part of speech and dependency trees are constructed.

4.2 Identification of affordance description

We adopt the format “transitive verb + noun or intransitive verb" in this framework, because the description formats with postfix "-ability" are seldom used by reviewers. With POS-tag, all the verbs in the informative sentences are targeted. The verbs like “be”, “have”, “wish”, “hope” are considered as uninformative verbs and are neglected, because they describe a status rather than an interaction. The remaining verbs are regarded as interacting verbs and are added to the affordance description. Adverbs which further describe interacting conditions should also be included in the description, if exist. If the verb is a transitive verb, the object of the verbs is also extracted to construct the entire affordance description. Adverbs and objects can be identified with POS-tag and dependency tree.

4.3 Identification of sub-assembly of product

The feature in the present sentence can be extracted with the help of feature extraction algorithms. A dictionary of feature words can help extract features from online reviews. If no feature word is found in the present sentence, the feature(s) in the previous sentence is considered, as reviews talk about a topic with continuity. In the case that no feature is found in the present sentence or previous sentences, the value of this element is the product.

4.4 Identification of user/artefact/environment

This element can be captured from the subject of the review sentences. The subject can be identified from dependency tree. If the subject is a human, then it is "user". If the subject is an artefact or environment, then the name of artefact or environmental material should be specified.

4.5 Identification of quality

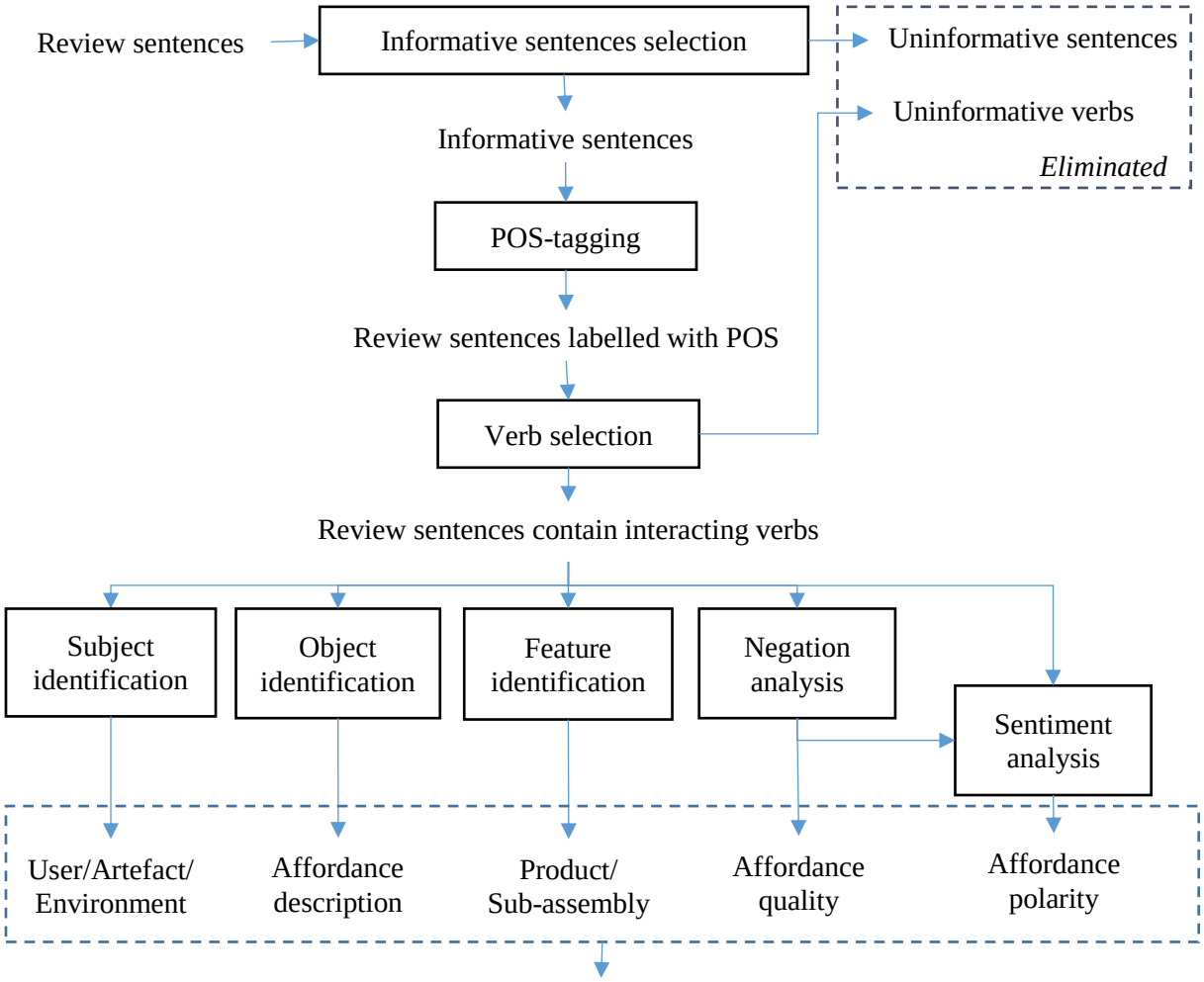
This element can be identified with the help of negation analysis algorithm. In the online reviews, reviewers only describe whether the product has potential ability to realise the desired interaction or not. Thus, we recommend having just two levels: "low (ability)" and "high (ability)". "Low" means the product cannot provide the described affordance, whereas "high" means that the product can provide that affordance. If a negation word (not, hardly, wish + could, etc.) is found in sentence, the affordance quality is "low", otherwise, the affordance quality is "high".

4.6 Identification of polarity

With sentiment analysis algorithm, the review sentences are categorised into three levels of satisfaction: negative, neutral and positive. The SENTRAL algorithm proposed by Raghupathi et al. (2015) provide a possibility to evaluate the overall satisfaction of the whole sentence. The algorithm begins with a dictionary of affect language (Whissler, 1989) that rates the sentiment of each review word. Then a series of basic heuristics are performed to calculate the overall sentiment rating. For the sentence in which the reviewer's sentiment is neutral, the polarity is marked as "not mentioned", because in this case it cannot be deduced. If the affordance quality is high, positive sentiment means that the affordance is "beneficial", negative sentiment means that the affordance is "harmful". If the affordance quality is low, positive sentiment means that the affordance is "harmful", negative sentiment means that the affordance is "beneficial".

4.7 Constructing structured affordance

After all the elements are extracted from online reviews, the affordance is finally formulated in the form as follows:
The [product or sub-assembly] provides [affordance polarity] affordance with [affordance quality] capable for the [user/artefact/environment] to [affordance description].



The [product or sub-assembly] provide [affordance polarity] affordance with [affordance quality] capability for the [user/artefact/environment] to [affordance description]

Figure 3 Synoptic of proposed framework

5 CASE STUDY: IDENTIFY AFFORDANCES OF KINDLE PAPERWHITE

To evaluate the proposed framework, a case study is performed with the online reviews of Kindle Paperwhite. Kindle Paperwhite is a product sold only online. Thus, a large amount of customer reviews is available. Kindle Paperwhite are designed to be used in various usage conditions, which means that the affordances mentioned in online reviews are more likely to be various.

We downloaded all the 5 most useful customer reviews from the product description page of Amazon.com, which means they are likely to contain more informative sentences. The reviews are compiled by 5 different reviewers. All the reviewers are recognized as owners of the product thanks to the label "verified purchase", which means they come out from real interaction between users and products. The length of reviews varies from 10 to 135 sentences and totalled 303 sentences.

5.1 Experiment design

The objective of experiment is to assess the effectiveness and repeatability of proposed framework to identify affordances from online customer reviews.

One expert in affordance based design and 6 participants are involved in the experiment. To prepare the experiment, as not all the participants are specialized in affordance based design, 15 minutes are devoted to training the concept of affordance and the identification framework.

During the experiment, first, the expert reads all the 303 review sentences and captures manually the affordances in them. Second, following the proposed framework, all the 303 review sentences are

analysed by the expert to capture affordances. Third, each participant analyses 20 consecutive review sentences randomly selected from the 303 review sentences following the framework. Thus, 120 (6×20) review sentences in total are analysed simultaneously by the experts and participants. In the fourth step, the identification results of expert and participant are compared through similarity analysis. The expert discusses the dissimilarities with participants, to make sure that the dissimilarities do not come from unconscious mistake. Finally, the expert and participants are interviewed to collect remarks (clarity of the definition of each element, difficulties following the proposed framework, etc.) on the identification framework.

To assess the effectiveness of the framework in identifying affordances from online reviews, the expert's manual identification results is compared with the expert's identification result following the proposed framework. Recall and precision rate are used as two main indicators. Recall is defined as the fraction of affordances that are identified, while precision is the fraction of identified affordances that are correct. It is obvious that higher the two indicators, better the effectiveness of the identification framework. The second objective of this experiment is to evaluate the repeatability of the proposed identification framework. Higher repeatability means higher possibility to automate the identification framework. The percentage of similarity between the participants' identification result and the expert's identification result following the proposed framework is an indicator. Higher similarity means a better repeatability of proposed framework.

5.2 Experiment result

From the expert's part, 133 affordances are captured from 91 review sentences. 58 sentences contain 1 affordance, 25 sentences contain 2 affordances, 7 sentences contain 3 affordances and 1 sentence contains 4 affordances. The identification result for each affordance element is listed in Table 2.

Table 2 Identification result of expert

	Affordance description	**Product or sub-assembly**	**User/artefact/environment**
Elements exist in review sentences	145	145	145
Elements capture by expert	133	133	133
Elements correctly identified	130	133	127
Recall rate	90%	92%	88%
Precision rate	98%	100%	95%
	Quality	**Polarity**	**Affordance**
Elements exist in review sentences	145	56	145
Elements captured by expert	133	56	133
Elements correctly identified	133	56	125
Recall rate	92%	100%	86%
Precision rate	100%	100%	94%

For the participant part, 50 affordances are captured from 41 sentences. 30 sentences contain 1 affordance, 7 sentences contain 2 affordances, 2 sentences contain 3 affordances. The identification result and comparison with expert's result for each element is listed in Table 3.

Table 3 Identification result of participants

	Affordance description	**Product or sub-assembly**	**User/artefact/ environment**
Elements captured by participants	50	50	50
Elements that are identical with expert	10	0	3
Similarity	80%	100%	94%
	Quality	**Polarity**	**Affordance**
Elements captured by participants	50	20	50
Elements that are identical with expert	0	0	11
Similarity	100%	100%	78%

6 DISCUSSION ON THE EXPERIMENT RESULTS

The whole experiment takes about 5 hours for the expert and 45 minutes for each participant, which means about 1 minute per sentence for the expert and 2 minutes for each participant. 125 affordances

are correctly identified using the framework by the expert from 91 informative sentences amount 303 review sentences. The result illustrates that comparing with other methods, identifying affordance from online reviews seems to be a better affordance identification method, especially better than the methods based on experimentation, because it is efficient and it consumes less resource.

We can conclude that the affordance identification framework is effective, as the recall and precision reach over 85%. The definition of affordance description is still to be detailed before automating the framework. Indeed, 20% of affordances description cannot be identified repeatedly. This number is rather high. Meanwhile, some difficulties are identified from the results and the interview of expert and participants.

1. Affordance described by an adjective cannot be identified by the framework

We found that not all the affordances are described with a verb. 10 affordances are defined by an adjective word with postfix "-able". For example, in the sentence below, it can be concluded that the Kindle Paperwhite affords the user the ability to notice the unevenness of background light. 2 affordances are described by other adjectives like "waterproof". That's why the recall of affordance description is not as high as other elements (90%).

Example: The unevenness of background light is noticeable.

2. Identification of subject in passive form and infinitive

As customer reviews are freely expressed, many sentences are written in passive voice. This makes the subject identification difficult because the subject is omitted. The same observation can be concluded for infinitives (to do). That is why the recall and precision of "user/artefact/environment" element (88% and 95%) are the lowest among all the elements. For example, in the sentence below, the participant has to read the whole sentence to determine the subject.

Example: This can be turned on or off if you find it distracting.

3. Identification of ironic tone

Ironic tone is often used by customers in online reviews to express their dissatisfaction towards the product. However, it cannot be tracked only by sentiment words. In this case, participants have to analyse the whole sentence, even previous sentence to make sure whether the reviewer express irony. Although the precision of "polarities" is 100% in the result, it is inherently difficult to process computationally.

Example: The Kindle Paperwhite 3 (released in 2015) is again a good e-reader that could have been just a little better.

4. Identification of informative sentence

The low similarity identification results of "affordance description" element between expert and participants (80%) suggests that a clearer definition of interacting verb is required. This observation is highlighted by expert and participants in the final interviews. For example, in the sentence below, the verb "forgot" looks like an interacting verb, as it involves the chargers and the user. However, by reading the adjacent sentences, we can figure out that "forget charger" is only a description of user's status. Thus, a robust categorisation of informative and uninformative sentences is needed to eliminate this kind of phrases when automating the framework.

Example: September 2015 update: I was on a week-long vacation trip but forgot my chargers.

7 CONCLUSION AND FUTURE WORK

To conclude, this paper discusses the theoretical basis and technical basis of using online review to identify affordances. Theoretically, the online reviews contain information on the interaction between user and product, and this is the basis of affordance concept. Technically, natural language processing algorithms should enable us to automatically identify affordances from online reviews. The advantage of using online reviews to identify affordances over existing identification strategies is also discussed.

Meanwhile, constitutive elements based on affordance ontology to structure the affordances in online reviews are proposed in this paper. Also, an affordance identification framework based on natural language processing is proposed. A case study with 303 online reviews of Kindle Paperwhite involving 1 expert and 6 participants shows that the proposed framework is effective. The framework provides basis for automating the identification process.

However, some problems remain in this research for automating affordance detection in customer reviews. First, due to the limit of time and resource, the process of framework is processed manually.

Thus, the efficiency and accuracy of natural language processing algorithms are to be verified in the future work. Second, the recall and precision of the framework can still be improved, as it is found that the adjective that describes the affordances usually possess postfix "-able".

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