A crowdsourcing development approach based on a neuro-fuzzy network for creating innovative product concepts

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Abstract

As an effective way to aggregate a crowd’s wisdom, crowdsourcing has attracted much attention in recent years. Especially for product innovation, crowdsourcing shows huge potential for generating more creative ideas in terms of quantity and innovativeness. However, there are still some deficiencies in the existing crowdsourcing work: i) lack of a crowdsourcing system under a systematic or unified framework to support product innovation; ii) lack of an effective quantitative method to assist the design of crowdsourcing tasks; and iii) insufficient anti-cheating measures in the initial stage of task design. In this article, a prototype crowdsourcing system is proposed to tackle these problems. Through the establishment of a task development model which consists of i) an innovation target analysis module, ii) an innovation-oriented HIT (human intelligent task) allocation module, and iii) a cheating control module, the proposed system is able to analyze and decompose the innovation target. In addition, it can identify suitable tasks to facilitate innovation and to embed anti-cheating measures in task design. To demonstrate the proposed prototype system, a case study on a future PC design is presented. Through control testing, it appears that the proposed system is effective in generating more valid and innovative ideas.

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1. Introduction

In new product development, a good product concept can bring about more opportunities to succeed in the fierce market competition. Amongst the most popular products today, Apple’s iPhone is regarded as a leading product in innovative design. Its unique and revolutionary design has gained tremendous advocacy worldwide. Inspired by Apple’s case, a number of studies have been conducted to explore the secrets of the successful development of innovative products. However, enterprises still face the challenges of developing innovative product concepts effectively.

Crowdsourcing is defined as ‘the act of a company or institution taking a function once performed by employees and outsourcing it to an undefined (and generally large) network of people in the form of an open call’ [15]. It is an important method to draw upon large numbers of people to contribute their knowledge. With the rapid development of the Internet, Web 2.0 provides an open platform to connect enterprises with worldwide consumers. Firms have more channels to communicate with users and can acquire useful knowledge from Internet users. Taking Proctor & Gamble as an example, the most challenging problems are solved by ‘InnoCentive’, and the problem solving rate has increased to 30%. In another example, Dell has set up an idea storm platform to collect comments and suggestions for all Dell products from Internet users. In addition, Wikipedia, Amazon’s Mechanical Turk and iStockPhoto.com are all good examples that take advantage of the tremendous numbers of Web users. Therefore, crowdsourcing appears to be a promising way to solicit external resources to improve product competitiveness.

Nowadays, a number of research studies have been devoted to crowdsourcing, the scope of which has covered the authentication of crowdsourcing’s power in acquiring useful data [3] and in the identification of factors which may influence the crowdsourcing effect [5]. Poetz and Schreier [24] conducted a study in which crowd workers showed stronger power to create innovative ideas. Regarding the task design methods, Khasraghi and Mohammadi [13] pointed out that crowdsourcing tasks should be distributed based on crowd workers’ interests and skills. In addition, the tasks can be designed with CAD/CAM (2D or 3D) to capture participants’ cognitive activities [19]. For the issue of cheating, some studies have been developed to detect cheating by organizing preference testing [32], calculating the reputation rank of participants [21], and investigating the relationship between the ‘meaningfulness’ of a task and a workers’ effort [9]. Considering the potential of crowdsourcing in supporting the creation of innovative concepts and emerging research effort in enhancing crowdsourcing methods,
it can be expected that a unified and improved crowdsourcing system, which systematically integrates the concerns of task design and cheating, may bring about more chances to achieve effective product innovation [1, 34].

Nevertheless, there are still three major research gaps in the current work: first, a crowdsourcing system under a systematic or unified framework for supporting product innovation has not been well addressed; second, it is imperative to attain an effective quantitative method to support the design of crowdsourcing tasks; and third, few anti-cheating concerns have been embedded in the initial stage of task design. Based on this understanding, a unified crowdsourcing system has been developed in this work. The proposed prototype system stresses a crowdsourcing task development model which is comprised of three cohesively interacting modules: namely, an innovation target analysis module; an innovation-oriented HIT (human intelligent task) allocation module; and a cheating control module. A case study on future PC design has been used to illustrate and validate the system.

2. Research background and related work

Crowdsourcing is a relatively new approach to aggregate the wisdom of the undefined online workforce. Compared with conventional product development approaches, the results of crowdsourcing depend on solvers’ education level, capability and initiative, however, crowdsourcing might be more efficient in knowledge acquisition. In this section, crowdsourcing is introduced from the following perspectives: (1) a brief overview of crowdsourcing, (2) potential of crowdsourcing for creativity, and (3) gaps in establishing a crowdsourcing system for creating innovative product concepts.

2.1. A brief overview of crowdsourcing

The term ‘crowdsourcing’ is a portmanteau of ‘crowd’ and ‘outsourcing’. It was first coined by Howe in the article ‘The Rise of Crowdsourcing’ in 2006 [15]. Actually, there were a number of notable examples that acquire the manpower of the crowd to accomplish tasks before this concept was proposed. As an example, the Oxford English Dictionary, which made an open call to the community for contributions to identify all words in the English language, received over 6 million submissions over a period of 70 years. This indicates that the power of the massive workforce is significant. Nowadays, the Internet is developing rapidly, and modern crowdsourcing has transferred mainly to the Internet.

Generally, crowdsourcing can be schematically depicted as in Fig. 1. As shown in Fig. 1, the employer/assigner (right side) submits a task (human intelligence task – HIT) to a mediator, viz. the crowdsourcing platform, and defines the requirements, reward rules, and task duration. Online workers/providers (left side) who are interested in this task can work on it and submit their solutions to the mediator after completion. These solutions will be forwarded to the employer who will pay the participants if their solutions are approved.

2.2. Potential of crowdsourcing for creativity

Florida [30] holds a view that creativity can be exhibited through ‘increased spending on research, high-tech startups, and a new social milieu, all converging in an age of pervasive creativity permeating all sectors of society’. In this regard, Cook [34] has a similar view that increased participation can be a contribution revolution as crowds may offer the potential for creativity.

Firstly, crowdsourcing is useful in devising innovative or better solutions. For example, Heipke [6] pointed out that the crowdsourcing technique is helpful to geospatial mapping and change detection in real time with considerable data at a low cost. In the same sense, the general public is also viewed as an important data source for hydrologic at measurements [25]. In the manufacturing industry, crowdsourcing brings about the chance to activate crowds to assist the identification of efficient product and material cycles [36]. In website building, crowdsourcing can be an efficient approach to usability testing [10]. Moreover, crowdsourcing has also been successfully used to obtain optimal resource planning [22] and to perform fast and reliable information retrieval [28].

The above reviews advocate that crowdsourcing appears very important in discovering better solutions using crowd wisdom, and various techniques are considered to be integrated to enhance the applicability of crowdsourcing. A new probabilistic graphical model was developed to jointly model the difficulties of the questions and the abilities of participants in grading collected solutions [40]. A novel method applying crowdsourcing and Human-Computation to tackle the problem of enumerating the stimuli–response space of a conversation was proposed [4]. Moreover, collective intelligence was coordinated to demonstrate the feasibility of crowdsourcing through helping individuals reappraise stressful thoughts and situations [31]. To model tasks with multiple-choice questions, a novel probabilistic graphical model was constructed to insert a decision-theoretic controller into the crowdsourcing process [7].

Furthermore, diverse studies have been emerging to optimize crowdsourcing, which were then exploited to ‘orchestrate’ crowdsourcing (i.e. controlling knowledge mobility, appropriability and innovation seeking organizations to improve stability) [14]. Bernstein et al. [26] presented an analytical method using queuing theory to minimize cost and improve performance for real-time crowdsourcing. Similarly, a mathematical analysis was considered to reveal the potential relations of costs and accuracy for a crowdsourcing platform [23]. A crowdsourcing data analytics system was developed to estimate the accuracy of generated results, verify the quality and reduce waiting time [39]. To offer more accurate and efficient crowdsourcing, a hybrid human–machine approach was used to relocate the jobs [16]. To incentivize high-quality outcomes in
crowdsourcing environments, endogenous entry is investigated, and it is shown that subsidizing the entry may improve the expected quality of the average contribution [2]. In addition, a learning algorithm was integrated to predict the wisdom of crowds and approximate crowd’s opinions [35]. A virtual valuation function, which depends on the distribution of contestants' skills and the number of contestants, was proposed to optimize crowdsourcing contests [33].

Based on the analysis of existing research, crowdsourcing shows the potential for creativity in terms of seeking creative solutions and developing creative crowdsourcing approaches. Therefore, it is worthwhile to explore crowdsourcing approaches to support product innovation.

2.3. Gaps in establishing a crowdsourcing system for creating innovative product concepts

Although the potential of crowdsourcing for creativity has been identified, gaps persist to develop crowdsourcing for supporting product innovation. The main problems to be overcome are:

- **Scarcity of effective crowdsourcing schemes to support product innovation** – Crowdsourcing is an important method to recruit a large number of workers. However, a typical scheme of crowdsourcing only provides a general outline of the connections between employers, Internet platforms, and online workers, which is actually a conceptual frame, and the concerns, especially for supporting product innovation, are few.

- **Lack of a systematic method to assist the design of crowdsourcing tasks** – Referring to existing crowdsourcing projects, HITs are often designed according to the instructions of the crowdsourcing platform. However, the question types provided by these platforms are fixed, and the limited question types may lead to employers’ negligence in the task allocation process. According to the theory and principles of questionnaire design [18], the question type and order have significant influences on survey results. Moreover, product innovation encourages participants to think and create freely. To stimulate innovative ideas, crowdsourcing tasks should have a proper openness to absorb diverse ideas, reasonable complexity to control participants’ burden, and scientific order to attract respondents’ attention. Thereby, task design deserves more exploration and should be deliberately handled.

- **Lack of a mechanism to control cheating** – Due to the anonymous nature of crowdsourcing, it is hard to guarantee the motivation and qualifications of crowd workers, and there is a risk of cheating. In a broad sense, cheaters can be defined as workers who do not meet the task requirements (e.g. do not follow instructions). There are clear incentives for workers to cheat: (1) reward; (2) duration; and (3) recreation. The majority of online workers are attracted by the monetary reward. To get a reward, they are prone to complete as many tasks as possible, which may result in cheating. Moreover, every project posted on crowdsourcing platforms has a fixed duration. Under time pressure, workers may rush to complete the tasks and sacrifice the quality of their response. Finally, there are also some participants who treat the crowdsourcing tasks as recreation and tend to cheat.

In allusion to these issues, a prototype crowdsourcing system is proposed in this work, which aims to establish a smooth and systematic crowdsourcing task development approach and embed anti-cheating concerns in the task design stage. It is expected that the proposed system can enhance the crowdsourcing effects and support the creation of innovative concepts.

3. Framework of the proposed crowdsourcing system

A framework of the proposed crowdsourcing system is presented in this section (Fig. 2). On the basis of a typical crowdsourcing scheme, the process for developing crowdsourcing tasks is stressed in this study. A crowdsourcing task development mechanism was established to bridge the gap between the project requirements and the specific crowdsourcing tasks. This mechanism mainly consists of an innovation target analysis module, an innovation-oriented HIT allocation module, and a cheating control module. The innovation target analysis module is developed to deeply analyze the project requirements and decompose the general target into specific innovation requirements on product features. Based on the particular requirements of every product feature/respect, an innovation-oriented HIT allocation module is developed to assign suitable tasks. Finally, a cheating control module is constructed to enhance the task design by formulating anti-cheating strategies at the initial stage of task design.

Conventional crowdsourcing is generated directly by developers according to project requirements, and lacks sufficient consideration of a reliable quantitative model to identify suitable tasks. Therefore, a task development model is needed to improve the task development process (Fig. 3). In general, the innovation target analysis module aims to identify the target participants, sort out product features to be designed, and estimate the allowed space for creativity (e.g. incremental or radical innovation). For the innovation-oriented HIT allocation module, it is a quantitative process to find the most suitable tasks which can best serve the creation and collection of innovative concepts (e.g. acquisition of novel designs). To improve the effectiveness of crowdsourcing,
a cheating control module with a set of measures and principles is formulated in the task design stage.

3.1. Innovation target analysis

To decompose the innovation goal hierarchically and organize these features systematically, a hierarchical architecture is established, as shown in Fig. 4. Overall, the innovation goal is analyzed from the following three aspects: (1) target participants, (2) product features, and (3) creativity space. In every aspect, specific dimensions/features are derived. Clearly, products in different categories may have very different features to be considered. This architecture is an attempt to formulate a strategy of how to decompose an innovation project into well-organized product features. Regarding the very specific features or dimensions, they need to be identified according to the requirements of different projects.

3.1.1. Target participants

The large number of online workers provides the advantage of crowdsourcing. However, more participants do not necessarily lead to better ideas. To make matters worse, there are also more noisy and chaotic data. In this sense, 'crowd' should refer to valid participation rather than the number of participants. Considering the success factor of conventional product innovation approaches (e.g. focus group, face-to-face interviews), there needs to be careful investigations into participants' qualifications, which indicates that the selection of qualified participants needs to be a critical concern of crowdsourcing.

According to the project requirements, target participants should be identified. For customer-oriented products, it is preferred that participants are also end-users. For example, to design an innovative baby feeding method, it is appropriate to invite mothers to participate. For technology-oriented product, participants with professional background are preferred. For instance, mechanical engineers are the target participants for innovation of mapping devices for a lathe. Generally, this procedure is the screening of suitable participants so as to achieve effective responses.

3.1.2. Features to be designed

The deployment of crowdsourcing tasks relies heavily on what product features are needed and how much space for creativity is allowed. It is strongly recommended that a clear feature list, which can provide the foundation for developing crowdsourcing tasks, should be given. Following the hierarchical structure of the features to be designed, the process to assign crowdsourcing tasks can be more manageable and systematic. In particular, it is better to list the product features so as to avoid missing any specific customer requirements [8].

3.1.3. Space for creativity

For different innovation projects, employers have different expectations about the degree of innovativeness (e.g. incremental
improvement or radical invention). Hence, a concept of ‘space for creativity’ is proposed in this work and defined through two parameters: ‘degree of innovation freedom’ and ‘constrained conditions’.

Degree of innovation freedom – This parameter is used to measure how much these features are expected to be improved and how freely they can be innovated. For example, if the appearance (e.g. size, shape, color) has a degree of innovation freedom of one hundred percent (100%) while the function design has a limited degree of innovation freedom ( < 100%), it indicates that employers are more concerned with appearance design than function design.

Constrained conditions – This parameter is used to point out the features which are not that necessary to be changed. For example, the basic configuration of a computer should be fixed, and innovation directions may be hidden in human computer interaction, interface design or new applications.

Through the innovation target analysis module, the features to be designed are organized in an orderly manner, and they are classified into innovation-free features and constrained features. In this way, it not only provides assistance to participants to innovate in a more effective way but also increases the opportunities to get valuable ideas.

3.2. Innovation-oriented HIT allocation

To support the creation of innovative ideas deserves careful consideration in identifying proper HITs to capture participants’ ideas and inspirations. In this section, the task allocation process is explained from i) examples of crowdsourcing task inputs; and ii) a neuro-fuzzy task allocation method.

3.2.1. Examples of crowdsourcing task inputs

According to Doan et al. [1], the contributions users can make are limited in many crowdsourcing systems. The basic task types include evaluating, sharing, networking, building artifacts, and acquiring original ideas from participants, and should not appear too frequently in one crowdsourcing project.

As presented in Table 1, the main tasks, which have been popularly used by existing crowdsourcing platforms, are organized into ranking. This ranking takes into account the openness of questions, the complexity of operations, and the experience of the task designers. Therefore, this ranking could represent the comprehensive difficulty in considering the above aspects.

### 3.2.2. A neuro-fuzzy task allocation method

In this work, a neuro-fuzzy approach is developed to assist the task allocation. Considering the inputs (viz. product features to be designed) and the output (viz. suitable task level), they are oftentimes described by linguistic terms such as ‘very complex’ or ‘highly difficult’. To cope with the qualitative descriptions, fuzzy methods are adopted. The method is depicted in Fig. 5, which mainly involves four layers, namely, the layer of crisp inputs, the layer of fuzzification, the layer of fuzzy rule base, and the layer of defuzzification.

Firstly, the linguistic terms/variables form the fuzzy sets. The layer of crisp input is to transform the fuzzy sets into crisp numbers which can be processed by membership functions. The fuzzification layer is the process of transforming the crisp inputs into membership degrees. For this layer, the key point is to define proper membership functions. According to the membership degree, fuzzy rules provide the reasoning evidence to derive the results under different conditions. At this stage, the establishment of the rule base should comprehensively consider related research.

### Table 1

List of crowdsourcing tasks.

<table>
<thead>
<tr>
<th>Task level</th>
<th>Tasks</th>
<th>Task level</th>
<th>Tasks</th>
</tr>
</thead>
<tbody>
<tr>
<td>VL</td>
<td>Single choice (from checkbox)</td>
<td>RL</td>
<td>Grid scale</td>
</tr>
<tr>
<td>L</td>
<td>Single choice (vote)</td>
<td>RL</td>
<td>Single slider</td>
</tr>
<tr>
<td>L</td>
<td>Evaluation through single choice</td>
<td>RL</td>
<td>Grid multiple choice</td>
</tr>
<tr>
<td>L</td>
<td>Classification through single choice</td>
<td>M</td>
<td>Evaluation through slider</td>
</tr>
<tr>
<td>L</td>
<td>Single choice (from dropdown list)</td>
<td>M</td>
<td>Single weighting with slider</td>
</tr>
<tr>
<td>L</td>
<td>Single scale</td>
<td>M</td>
<td>Grid multiple choice (with categories)</td>
</tr>
<tr>
<td>L</td>
<td>Multiple choice (from check box)</td>
<td>M</td>
<td>Multiple choice (combine text)</td>
</tr>
<tr>
<td>L</td>
<td>Multiple choice (vote)</td>
<td>M</td>
<td>Grid slider</td>
</tr>
<tr>
<td>L</td>
<td>Single number entry</td>
<td>RH</td>
<td>Grid number entry</td>
</tr>
<tr>
<td>L</td>
<td>Evaluation through multiple choice</td>
<td>RH</td>
<td>Grid weighting slider</td>
</tr>
<tr>
<td>L</td>
<td>Classification through multiple choice</td>
<td>RH</td>
<td>Grid text entry</td>
</tr>
<tr>
<td>RL</td>
<td>Grid single choice</td>
<td>H</td>
<td>Sequencing</td>
</tr>
<tr>
<td>RL</td>
<td>Grid single choice (with categories)</td>
<td>VH</td>
<td>Upload</td>
</tr>
<tr>
<td>RL</td>
<td>Simple words entry</td>
<td>VH</td>
<td>Paragraph text</td>
</tr>
<tr>
<td>RL</td>
<td>Single choice (combine text)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(VL=very low, L=low, RL=rather low, M=medium, RH=rather high, H=high, and VH=very high.)
expertise and existing publications in order to achieve reliable fuzzy rules. Finally, the defuzzification layer integrates the results of fuzzy rules and quantifies the results into a numerical format.

Regarding the task design, the type of task is the primary concern. Generally, tasks can be classified into open and closed questions [12,38]. Considering the demand of an innovation project, the openness of tasks should be deliberately determined to stimulate respondents’ inspirations. Moreover, the task difficulty, respondent ability, and respondent motivation are three major factors in questionnaire design [17,18]. This leads to awareness in HIT design to set the operations with proper complexity and fully take the need for cognition into consideration. In this regard, Rampino also highlighted the importance of participants’ cognitive abilities and emotional reactions [20]. Based on the analysis, the inputs are decomposed into three dimensions which represent the most crucial concerns of task design: i) the degree of innovation freedom which is related to the openness of the task to acquire innovative opinions from participants, ii) human input in terms of operations which considers the complexity of operations to complete the task, and iii) human input in terms of attention which reveals the cognitive ability and seriousness required to be paid to this task. Therefore, every feature can be defined through three dimensions and are denoted as ‘degree of freedom, required human input in terms of operation, and required human input in terms of attention’.

For membership functions, the commonly used membership functions are: i) the combination of trapezoid functions and triangle functions (Fig. 6); and ii) the combination of general bell functions and Gauss functions (Fig. 7). As fuzzy systems are highly tolerant of the approximation of function shape, the identification of the membership function is not focused on. To simplify the computation, the Trap-Tri-Trap and Gbell-Gauss-Gbell functions are adopted as the membership functions in this work.
The function shape and corresponding equations are presented below.

\[
y = \begin{cases} 
1; & 0 \leq x \leq a \\
\frac{x-a}{b-a}; & a \leq x \leq b \\
\frac{c-x}{d-c}; & c \leq x \leq d \\
\frac{d-x}{d-c}; & 0.5 \leq x \leq d \\
1; & f \leq x \leq 1
\end{cases}
\]  \hspace{1cm} (1)

Fuzzy rules are generated based on expertise, designers’ experience, lessons from practical cases, and indications from related research and publications, so that they are reliable to handle qualitative variables with concerns in fuzziness. The normal grammar of a fuzzy rule is

‘IF A is high and B is high and C is high
\hspace{1cm} THEN D is high’

IF states the conditions which comprise a series of facts, and THEN states the results. This rule can be interpreted as: when the ‘degree of freedom’ is ‘very free’, the ‘required human input in terms of operation’ is ‘very complex’, and the ‘required human input in terms of attention’ is ‘very serious’, then the task that should be assigned in such conditions is ‘high-class’.

The operations between different facts are basically ‘AND’ and ‘OR’. ‘AND’ is the intersection and ‘OR’ is the union.

\[\text{AND : } A \cap B; \hspace{0.5cm} \text{OR : } A \cup B\]

Nevertheless, there are some errors and biases in fuzzy rules owing to the nature of personal experience and knowledge. To rectify errors and improve the reliability of fuzzy rules, a back-propagation weighting training process is developed to optimize the fuzzy system (Fig. 8). Different weights are assigned to different rules. Through loading training sets and comparing the difference between ideal and actual outputs, the weights are continuously revised until the difference remains stable, and the weights can be regarded as optimal weights.

\[e_k(p) = y_{d,k}(p) - y_k(p)\]  \hspace{1cm} (3)

where \(e_k(p)\) is the error between the ideal and actual output at the \(p\)th iteration, \(y_{d,k}(p)\) is the expected result of the \(k\)th neuron at the \(p\)th iteration, \(y_k(p)\) is the actual result of the \(k\)th neuron at the \(p\)th iteration.

\[
\delta_k(p) = \frac{\partial y_k(p)}{\partial x_k(p)}
\]

where \(\delta_k(p)\) is the error rate of the \(k\)th neuron at the \(p\)th iteration, \(y_k(p)\) is the output function, \(y_k(p)\) is the actual result of the \(k\)th neuron at the \(p\)th iteration.

\[
\beta(p) = \text{sgn}(e_k(p)) = \begin{cases} -1, & e_k(p) < 0 \\
0, & e_k(p) = 0 \\
1, & e_k(p) > 0
\end{cases}
\]

where \(\beta(p)\) is the direction of the weight correction.

\[
\Delta w_k(p) = \alpha \beta(p) y(p) \delta_k(p)
\]

(6)

where \(\Delta w_k(p)\) is the weight correction, \(\alpha\) is the learning rate.

\[w_k(p+1) = w_k(p) + \Delta w_k(p)\]

(7)

For training sets, they can be the limit case data. For example, the inputs are \(x_1 = [1, 1, 1]^{-1}\), \(x_2 = [0, 0, 0]^{-1}\), and ideally the outputs are \(y_1 \in [0.9, 1], y_2 \in [0, 0.1]\).

However, the neural network, with a back propagation algorithm, is slow to converge and easy to fall into a local minima in training. Considering this drawback, a method proposed by Dai and Liu [29] is employed in this work to assist in achieving the optimal solution. Generally, all local mimina points will be saved as possible solutions and the most desirable solution will be selected competitively from all possible solutions. Besides, over-fitting is also a common problem confronted in neural network with few hidden neurons. To tackle this problem, the penalty method is considered, and a penalty term is derived and added to the error function to improve the generalization capability of this network.

Defuzzification is a process to combine the results of fuzzy rules and to quantify the result into numerical format. As shown in Fig. 9, the effect of every fuzzy rule is calculated according to the operation of the rule, and the union of all these effects is the effect area of the final result. To quantify the final effect, the commonly applied method is to calculate the centroid. The reference equations are listed below to help explain the defuzzification process.

\[Y = \bigcup_{i=1}^n Y_{R_i} \cup \bigcup_{j=1}^m Y_{R_j} \cup \bigcup_{l=1}^p Y_{R_l}\]  \hspace{1cm} (8)

where \(Y_{R_i}\) is the effect of rule 1, \(Y_{R_k}\) is the effect of rule 2, \(Y_{R_l}\) is the effect of rule 3, and \(Y\) is the aggregation of effects of three rules.

\[y = \text{centroid } (Y) = \frac{\int_a^b \mu(x)dx}{\int_a^b \mu(x)dx}\]

where \(\mu\) is the membership function of output, \(a\) and \(b\) are respectively lower and upper limit of \(x\) value of \(Y\).

In general, this neuro-fuzzy method is developed to utilize fuzzy methods to arrange proper tasks which can best solicit respondents’ ideas according to the requirements on product features.

3.3. Cheating control measures/principles

Cheating is one of the most important issues of crowdsourcing due to the anonymous nature of participation. To reduce cheating and improve the effectiveness of the proposed model, a set of measures/principles are formulated to embed anti-cheating concerns in the initial stage of crowdsourcing development by enhancing task design.

3.3.1. Proper task order

A reasonable arrangement of HITs can make participants feel comfortable and keep them enthusiastic during participation. However, it is hard for participants to concentrate on every task.
Thus, the order of tasks should be carefully determined so as to effectively collect solutions to questions of different importance. For example, questions on the same topic should be grouped together. Questions on sensitive topics that might make respondents uncomfortable should be placed at the end of the questionnaire [18]. To force participants to slow down and pay more attention to important tasks, questions assigned can be more difficult or complex e.g., blank filling requires more attention for completion than single choice questions.

Moreover, it is suggested to arrange similar questions randomly to test whether participants’ answers are consistent. If not, it provides a hint that the participants probably completed these tasks randomly, and the solutions may not be valid. For these questions, ‘gold units’ (i.e. questions with absolute correct answers) are often adopted [32].

3.3.2. Verification questions
Apart from setting an appropriate task order, verification questions are recommended to help further reduce cheating. Generally, verification questions are additional tasks which are inserted to test the performance of respondents. For example, employers can assign basic background questions to test whether the participants have really understood the requirements/instructions and thereby judge whether they are able to give valid responses.

3.3.3. Building rapport
Another important factor which may result in cheating is the participation experience. If participants lose interest in completing a crowdsourcing project, they may be prone to cheat or complete perfunctorily. For example, work load is one concern for building rapport. If the task load is too heavy, it will sap participants’ enthusiasm and force them to cheat to finish this project as soon as possible. Generally, a relaxing and harmonious user experience for participants should be ensured.

Through the establishment of the three modules, the proposed crowdsourcing system is expected to (i) decompose the innovation target, (ii) identify the most suitable tasks, and (iii) reduce cheating through improved task design.

4. A case study on future PC design
In this section, a crowdsourcing project is presented and illustrated. The project theme is about an innovation case study on ‘LifeBook: what PCs will be like in the near future’ by Fujitsu (LIFEBOOK is Fujitsu’s laptop PC series with the concept of Life Partner – ‘Always standing by your LIFE’). The proposed crowdsourcing system will be implemented with the same topic. At the same time, the crowdsourcing results of Fujitsu’s project using a typical crowdsourcing scheme (data can be collected via the website of designboom) will be analyzed as a control group to be compared with our proposed system. The main differences between a typical crowdsourcing with the proposed crowdsourcing system are presented in Table 2.

Regarding this project, the general descriptions of the objectives and requirements have been outlined as,

‘With the spread of ICT, the ability for people to make diverse connections via networks with other people in all daily life situations have increased through a variety of devices such as PCs and smart phones. As a provider of ICT products and services, Fujitsu strives to create a new society that contributes to people’s everyday lives. Our aim is to make computing technology a familiar part of people’s life so that it may be used conveniently by as many people as possible. This competition is held to make the future lifestyle of people richer and even more fun, and to give a concrete shape to the future as Fujitsu sees it by promoting the use of the ever-changing technology and dramatically expanding the possibilities of our services.

- The LIFEBOOK category which studies what PCs will be like in the near future
Applicants are reminded to think about possible situations where the PC may be used and to express the ideal next-generation computing device of the future as you see it. The requirements are that it is a mobile device that can be carried around and that it can be operated through a network using computing technologies. LIFEBOOK’s brand concept: the four values innovation: Innovation: That it is innovative
Reliability: That it is highly reliable
Human Centric: That the design focuses on the user
Green: That it is friendly to the environment.

- Design criteria
LIFEBOOK Category is the design focusing on the user (human-centered design)?
 Does it have sufficient novelty and appeal as a product design?
 Has feasibility been considered?
4.1. Innovation target analysis

According to the information, the target is a future PC product. Firstly, the innovation target is analyzed from the respect of target participants, main features to be designed, and the space for creativity. For target participants, they should be PC users. The main features covered by a PC design are shown in Fig. 10. For every feature, it is denoted as ‘Feature (degree of freedom, required human input in terms of operation, and required human input in terms of attention).’

According to the requirements of this project, the scenarios on how a PC can be used are stressed, so usage scenarios are free to be created. For overall physical attributes, they are not the focus of this project, but the product is required to be a mobile device that means this product should be highly portable. Hence, ‘size’, ‘weight’ and ‘shape’ are partly free. ‘Color’ is surely free to be designed. For the hardware and interface, the basic configurations should be fixed, as they are technical issues and beyond the scope of this innovation. Nevertheless, to match the special scenarios proposed by participants, additional accessories and software applications are assigned with some freedom for innovation. The ‘basic functions’ that a PC should be equipped with (e.g. accepting data, displaying data) are regarded as basic attributes, and ‘exciting functions’ (i.e. functions beyond the expectations of users) are considered to support the creative design.

Considering the estimation of the three dimensions, it is complex to quantify and measure product features, especially intangible features (e.g. color). Thus, fuzzy sets, which are highly tolerant of approximation, are employed. In this study, 5 levels (L=low, RL=rather low, M=medium, RH=rather high, H=high) are set for innovation freedom, and 3 levels (L=low, M=medium, and H=high) are assigned to human inputs in terms of operations and attention. 7 levels are assigned to output (VL=very low, L=low, RL=rather low, M=medium, RH=rather high, H=high, and VH=very high).

4.1.1. Innovation-oriented HIT allocation

For the membership functions, the typical Trap-Tri-Trap membership function is adopted to describe the inputs ‘Human input in terms of attention’.
terms of operations’ and ‘Human input in terms of attention’) and output (‘Task level’) (Table 3). ‘Innovation freedom’ is the focus of this project. Thus, it needs to be estimated carefully. To embody the complex influences caused by multiple factors (e.g. expertise, definition of innovativeness) and improve the approximation of the membership degree function of innovation freedom, nonlinear functions are preferred as mentioned in Section 3.2. The general bell function and Gauss function are the commonly adopted nonlinear membership functions and deployed for ‘Innovation freedom’ in this study.

Subsequently, fuzzy rules are generated. Through continuous revisions and improvements, a rule base with totally 34 fuzzy rules is built. The surface views of the rule base are presented in Fig. 11.

However, linguistic inputs should be transformed into numeric format which can be processed by the fuzzy system. To give a more accurate estimation, we use a range to represent the linguistic variable and compute the average value as the crisp input. Therefore, the three-dimension of inputs are obtained, as shown in Table 4. The output is obtained through the fuzzy system.

4.1.2. Cheating control measures/principles

During the task design, the measures/principles to control the cheating phenomenon are implemented. The HITs generated by the above step are arranged by importance. The important questions are placed at the beginning, so that the participants have enough enthusiasm to carefully deal with these questions. To illustrate, the task of ‘outlining the characteristics of your concept and specifying the features which are unique and special’ is one of the most important tasks and put in the first half of the crowdsourcing tasks. Furthermore, the mood of the participants should also be considered during sequencing these tasks. The sensitive questions which may make respondents uncomfortable should be arranged at the end, and vice versa. For example, the question ‘What is the greatest motivation for you to participate in this project? (1) Interest; (2) Killing time; (3) Monetary reward’ is put in the last section. Similarly, some questions related to personal privacy are also put at the end.

**Table 3**
Collection of membership functions.

<table>
<thead>
<tr>
<th>Input variables</th>
<th>Membership functions</th>
</tr>
</thead>
</table>
| Innovation freedom | L – Gbell [0.22, 3, 0]  
M – Guass [0.1, 0.5]  
RH – Guass [0.065, 0.7] |
| Human input in terms of operations | L – Trap [0, 0.4, 0.6]  
M – Tri [0.4, 0.6, 0.8]  
H – Trap [0.6, 0.8, 1, 1] |
| Human input in terms of attention | L – Trap [0, 0.1, 0.4]  
M – Tri [0.2, 0.5, 0.8]  
H – Trap [0.6, 0.8, 1, 1] |
| Output variable | Task level |
| VL – Trap [0, 0.05, 0.3]  
L – Tri [0, 0.2, 0.4]  
RL – Tri [0.25, 0.35, 0.45]  
M – Tri [0.3, 0.5, 0.7]  
RH – Tri [0.55, 0.65, 0.75]  
H – Tri [0.6, 0.8, 1]  
VH – Trap [0.7, 0.95, 1, 1] |

**Fig. 11.** (a) Surface view of x-Innovation freedom, y-Human input in terms of operations, and z-Task level; (b) surface view of x-Innovation freedom, y-Human input in terms of attention, and z-Task level.

**Table 4**
List of inputs and outputs data.

<table>
<thead>
<tr>
<th>Design features</th>
<th>Fuzzy sets</th>
<th>Crisp input</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Usage scenario</td>
<td>(H, H, H)</td>
<td>(0.8<del>1, 0.6</del>0.8, 0.8~1)</td>
<td>(0.9, 0.7, 0.9)</td>
</tr>
</tbody>
</table>
| Overall attributes | Weight (M, L, H)  
Size (M, L, H)  
Color (H, L, H)  
Shape (H, L, H) |
| Hardware | Regular parts (L, L, L)  
Others (RH, M, H) |
| Interface | Operation system (L, L, L)  
Software application (RH, M, L) |
| Functions | Basic (L, L, L)  
Exciting (H, M, H) |
Secondly, some verification questions are randomly inserted to (i) detect the background of participants (e.g. whether they are able to provide valuable information); and (ii) test the performance of participants (e.g. whether they have understood the instructions). In particular, persons who have related knowledge and experiences about PCs and product design are the target participants for this project, so questions are designed such as ‘Could you provide at least one computer technology which impressed you the most in recent years?’, and ‘From your experience so far, please describe a time when you were involved in a design project or related activities’. In addition, verification questions are designed to test whether participants’ answers are consistent. For instance, the questions ‘In the following two designs, which one is more user friendly?’ and ‘In the following two designs, which one is not user friendly?’ appear randomly to test whether the participant gives answers randomly.

Finally, the task load should be controlled at a proper level, and the user interface should be friendly. Overall, one day is enough to complete this project. There is no upper limit, if the participants would like to generate CAD models or prototypes.

4.1.3. Evaluation of innovative concepts

Based on the HIT allocation results and the concerns of cheating control, suitable tasks could be arranged, and the whole crowdsourcing HITS can be built accordingly. The crowdsourcing HITS generated by the proposed system and the crowdsourcing using the typical scheme are both posted on the web, so that control testing can be conducted to validate the proposed crowdsourcing system.

To have the innovative concepts from the crowd, an evaluation process of innovative concepts is executed, and the most innovative concepts are selected as approved solutions to be rewarded. For this purpose, there have been some methods which are useful and effective, such as Pugh method, Analytic Hierarchically Process (AHP), and Quality Function Deployment (QFD) matrix method [11,27,37]. To organize the evaluation process hierarchically and stress the decision making, the commonly used AHP method is adopted. Based on the criteria which have been set by the project assigner (i.e. human-centered, novelty, feasibility, reliability), the performances of these concepts are assessed by a focus group which involves designers and Ph.D. students in the industrial and engineering design area. Based on their professional opinions, a relatively comprehensive comparison can be obtained. The general structure of AHP applied in evaluation process is presented as shown in Fig. 12.

Where DP: default priority; DP1 + DP2 + DP3 + DP4 = 1.000.

4.1.4. Results and analysis

A comparison in terms of the quantity and quality of crowdsourced solutions is presented (Table 5).

Through this control testing, the results show that the proposed prototype crowdsourcing system performs better than typical crowdsourcing (Table 5). Firstly, the ‘percentage of valid solutions P1’ is improved and implies that the cheating control module may be helpful to reduce the cheating phenomena. Secondly, the proposed crowdsourcing has more chances to get qualified solutions. Differing from valid solutions, qualified solutions are defined as solutions which are firstly not cheating and then meet the innovation requirements. In this case, the qualified solutions should be the valid solutions with certain creativities. Through observing the parameter ‘Percentage of qualified solutions P2’, it can be found that the proposed crowdsourcing system is more effective to get useful ideas. This improvement indicates that the innovation target analysis module may be useful to sort out target participants (i.e. who are more possibly able to provide useful knowledge) and generate more valuable solutions. Thirdly, there are more opportunities to reach excellent innovative ideas through the proposed crowdsourcing system. It can be seen P3 is improved by the proposed system, which implies that the HITS generated by the proposed method can be more effective in collecting creative ideas from participants. Based on the analysis of the results, the proposed crowdsourcing system is helpful to support the creation of innovative ideas.

Table 5

<table>
<thead>
<tr>
<th>Comparison</th>
<th>Typical crowdsourcing scheme</th>
<th>Proposed crowdsourcing system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of collected solutions</td>
<td>76</td>
<td>59</td>
</tr>
<tr>
<td>Number of valid solutions (no cheating)</td>
<td>69</td>
<td>56</td>
</tr>
<tr>
<td>Percentage of valid solutions P1</td>
<td>69/76 = 90.79%</td>
<td>&lt; 56/59 = 94.92%</td>
</tr>
<tr>
<td>Number of qualified solutions P2</td>
<td>60</td>
<td>51</td>
</tr>
<tr>
<td>Percentage of qualified solutions P2</td>
<td>60/69 = 86.96%</td>
<td>&lt; 51/56 = 91.07%</td>
</tr>
<tr>
<td>Number of excellent innovative solutions P3</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>Opportunities to reach excellent innovations P4</td>
<td>6/69 = 8.70%</td>
<td>&lt; 7/56 = 12.5%</td>
</tr>
</tbody>
</table>

(Valid solutions = solutions with no cheating detected; Qualified solutions = solutions which meet innovation requirements; Excellent innovative solutions = solutions which are qualified and have the best innovativeness.)
5. Discussion and conclusions

By and large, this research is intended to improve crowdsourcing system to support the creation of innovative product concepts. Based on an analysis of previous work, three problems are identified as (1) a crowdsourcing system under a systematic or unified framework for the purpose of supporting product innovation has not been well addressed; (2) it is imperative to attain an effective quantitative method to support the design of crowdsourcing tasks; and (3) few anti-cheating concerns have been embedded in the initial stage of task design. To tackle these problems, a crowdsourcing system is proposed. In particular, a task development model is emphasized which consists of three modules: i) an innovation target analysis module, ii) an innovation-oriented HIT allocation module, and iii) a cheating control module. To realize these modules, a hierarchical architecture is structured to assist the decomposition of the target. A neuro-fuzzy approach is developed to identify suitable crowdsourcing tasks. In addition, a set of measures/principles is formulated to integrate anti-cheating concerns at the HIT design stage. Through control testing of an innovation project of a future PC design, the proposed crowdsourcing shows the potential to generate more innovative solutions are improved by the proposed system, there are still some limitations. Firstly, the total number of participants is not as large as in typical crowdsourcing. As the proposed crowdsourcing system integrates lots of concerns about task design and cheating, the task load and difficulty are relatively heavier than in typical crowdsourcing, so that the proposed crowdsourcing seems not that attractive. Nevertheless, the attraction could be made up through other means, such as increasing the rewards. Secondly, the technique used in the proposed system can be further improved to enhance the reliability and accuracy. Therefore, it is envisaged that more efforts need to be placed on explorations for increasing the attraction of the proposed crowdsourcing system and in improving the mathematical methods in the future.

References

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