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Explore technology innovation and intelligence for IoT (Internet of Things) based eyewear technology

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ABSTRACT

Advances in wireless Internet and mobile communications devices have driven significant development in the Internet of Things (IoT), bringing a stream of innovative technologies and services. This study explores the technology innovation and intelligence for IoT (internet of things) based eyewear technology. This study proposes a two-stage patent analysis based on the quality function development (QFD) method which adopts customer requirement and technology viewpoints to explore key technologies. This methodology can recognize the specific technologies with development potential in the eyewear industry, and identify holders of key relevant patents. This study finds that consumers value functions including motion tracking, reminders, eye state detection, and non-eye disease detection. Key technologies with development potential for satisfying customer demand include eyewear, communications protocols, and sensors. Thus, embedding micron-scale sensors directly into contact lenses to monitor user physiological data can satisfy customer demand and is considered as emerging technology in the smart eyewear industry. Furthermore, patent portfolios of these technologies vary among different countries and regions, with the US and EU focusing on eye tracking, motion tracking, and identity verification, while China focuses on eye fatigue detection, distance measurement, and wireless frequency technologies. Visualizations of overall research results can benefit eyewear-related patent holders, eyewear manufacturers and smart wearable manufacturers to build their patent portfolio strategies on the basis of regional or country considerations.

1. Introduction

The Internet of Things (IoT) uses implanted or attached microsensors to integrate objects into wireless networks allowing objects to interact with one another, and for people to interact with objects, thus ensuring a reliable and continuous exchange of relevant information to improve quality of life (Chang and Chen, 2014). Advances in communications technology, sensing devices and big data processing techniques have driven the expansion of the IoT into smart home applications, environmental monitoring, healthcare, inventory management, public security, smart transport and smart logistics (Atzori et al., 2014; Li and Chen, 2012).

Increasing health consciousness is leading people to be more aware of their physical condition. A variety of physiological signals can be recorded and tracked to help users engage in physical exercise, promote overall health, obtain early disease detection, and treat medical conditions, but traditional physiological measurements are taken on a regular, rather than continuous, basis, and thus lack immediacy and continuity which may help to reveal subtle health changes (Wu and Wang, 2014).

According to Topology Research Institute estimates, by 2018, total global output of smart medical services, including remote monitoring, diagnostic equipment, assisted living and physiological data tracking, will exceed US$30 billion, and that the market for such products and services will expand by 60% annually from 2016 to 2018 as shown in Fig. 1.

Smart Wearables definitely offer unprecedented opportunities for tackling pressing societal challenges by providing solutions in the areas of healthy ageing, patient monitoring and others (European Commission, 2016). According to International Data Corporation (IDC), several categories of wearable such as wrist wear, modular, clothing, eyewear, ear wear and more emerged onto the consumer scene for the wearable ecosystem. Smart eyewear, a wearable computing device, is web-connected and enables to transmit multiple types of data and project it in field of vision. Head - mounted displays can react on voice comments, eye movements, gestures or simple tactile commands (Wrzesińska, 2015). The shipments of smart eyewear were 1 million in 2015 and are predicted to be 4.5 million in 2019 and account for almost

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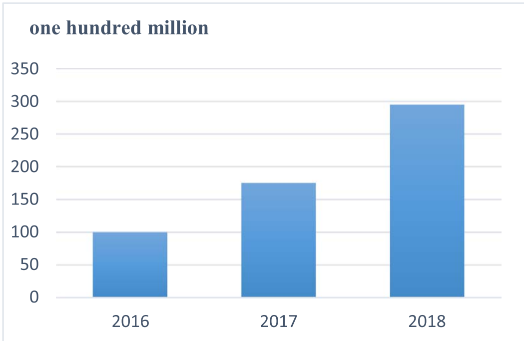

Fig. 1. Estimated global smart medical services output, 2016–2018. (Topology Research Institute, 2015)

Table 1
Fuzzy number transformation.

Importance/correlation level	Fuzzy number (α, β, γ)
Very high	(0, 1, 2)
High	(2, 3, 4)
Medium	(4, 5, 6)
Low	(6, 7, 8)
Very low	(8, 9, 10)

4% of wearable devices (Richter, 2016).

Moreover, medical diagnostics is expected to lead the application market of smart eyewear. MarketsandMarkets (2015) reported that the eye tracking market is estimated to reach USD 1028.1 Million by 2020, at a Compound annual growth rate of 35.2% between 2015 and 2020. Furthermore, a combination with smart contact lens and eyeglass could be used to monitor diabetes and deliver drugs and mean an end to the painful finger pricks diabetics endure (Patel, 2016).

The present study proposes an integrated patent analysis and two-stage quality function deployment method to explore smart eyewear applications such as medical diagnostics of eye tracking, eye state tracking and other conditions. This study can identify directions for future deployment of patents and technology positioning relevant to the IoT based eyewear industry. The results will provide a reference to the eyewear industry to grasp future development trends for innovative industry management.

2. Literature review

2.1. Internet of Things

The concept of the IoT was first proposed by Bill Gates in his 1995 book "The Road Ahead". The term was used to describe the development of smart homes. However, given the immaturity of the required technologies, the term did not attract much attention at the time. In 1999, Kevin Ashton, director of the MIT Auto-ID Center used Radio Frequency Identification (RFID) as the basis for wirelessly linking recognition technology devices through the Internet to exchange information, thus achieving "smart" identification and operations management for IoT information.

Following definitions from the European Telecommunications Standards Institute (ETSI), the IoT work content can be classified as belonging to the perception level, the network level or the application level.

1. Perception layer: Devices feature sensing, identification and communication capabilities and are used for sensing and monitoring through the use of sensors, RFID tags and RFID readers.

2. Network layer: Data collected at the perception layer is transmitted to networked storage and computation resources to achieve interconnection and sharing of objects. A variety of network communication technologies are used, including RFID, ZigBee, Bluetooth and WiFi.

3. Application layer: Software applications are developed to satisfy different user needs, using data sourced from the perception layer via the network layer. These applications are designed for use in different environments, such as collecting road congestion information for use in smart transport applications, providing the user with real-time information on driving conditions.

As to the IoT Software applications, its impact on medicine will be perhaps the most important, and personal effect. Wearables devices today support fitness, health education, symptom tracking, and collaborative disease management and care coordination. All those platform analytics can raise the relevancy of data interpretations, reducing the amount of time that end users spend piecing together data outputs (Dimitrov, 2016; Lexinnova, 2016). As mentioned before, medical diagnostics of smart eyewear have a great economic impact, and thus this study has focused on the eyewear integration of IoT applications.

2.2. Fuzzy quality function deployment

Quality function deployment (QFD) is a planning tool used to fulfill customer expectations. The structure of QFD can be thought of as a framework of a house (House of quality, HOQ). The exterior walls of the house are the customer requirements. On the left side is a listing of the voice of the customer, or what the customer expects in the product (Whats). The ceiling of the house contains the technical descriptors (Hows) (Lampa and Mazur, 1996). This system is specifically aimed at maximizing customer satisfaction by generating information about customer needs, and translating this information into actions and designs. The interior walls of the house are the relationships between customer requirements and technical descriptors.

When applying QFD, the degree of the importance of customer requirements and the correlation matrix might be derived from interviews. These data are characterized by ambiguity and are thus difficult to quantify. The concept of fuzzy sets can solve this problem. Fuzzy Theory allows for the development of mathematical descriptions of fuzzy concepts, such as human language (Lin et al., 2014). A fuzzy number is represented by its parameter in the characteristic functions. A triangular fuzzy number is denoted as (α, β, γ). Parameters α, β and γ represent the smallest possible value, the most promising value, and the largest possible value of a fuzzy event respectively (Kazancoglu and Aksoy, 2011). To rank fuzzy numbers, they should be transformed into crisp values, which is a defuzzification process. This paper adopts the center of gravity method to defuzzify fuzzy numbers following the triangular fuzzy membership function (Chen and Chen, 2003; Wang and Chow, 2016). The fuzzy number transformation is shown in Table 1.

This paper applies fuzzy QFD to explore important IoT techniques from the perspectives of customer requirements.

2.3. Patent intelligence

A patent is a type of intellectual property right in which governments grant inventors (assignees) an exclusive right for a length of time (20 years) to make, use, offer for sale, or sell an invention (Marinova and McAleer, 2003). A patent document consists of technical information. Thus, patent counts and patent citation analysis are often used as an indication of technology development trends. Analysis of patents provides researchers with insights into the directions of technical development of a given company, of an industry in a given country, or globally (Lee et al., 2016).

Patent indicators are the results of statistical analysis of patents. Patent indicators can be classified into three types: general characteristics patent indicators, patent citation indicators and technical patent indicators. General characteristics patent indicators such as patent number, patent issue date describe a patent from the perspective of the

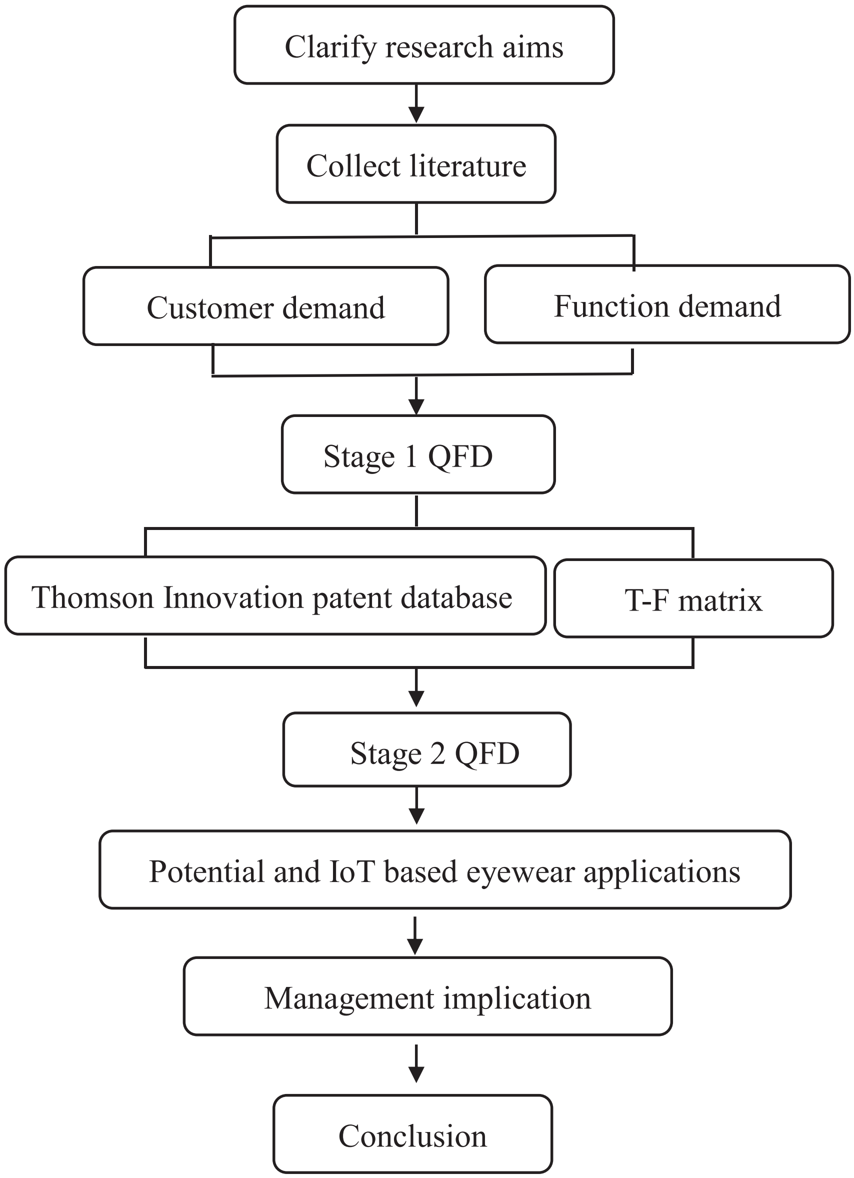

Fig. 2. Research framework.

patent owner. Patent citation indicators include information on patents cited within other patents; while technical patent indicators focus on a patent's technical characteristics (Yuan and Liang, 2009). Patent number and citation indicators will be applied in the correlation of the patent T-F matrix in the second stage QFD.

3. Research methodology

QFD has been used as a tool for listening to the voice of the customer (Voc) and extending quality into the design of products, processes, and production systems. Therefore, the quality of all of the aspects of an organization is guaranteed to be customer driven. However, simple QFD relies too heavily on experience, and thus, needs to complement with other analytic tool. Furthermore, analysis of patents provides researchers with insights into the directions of technical development of a given company, of an industry in a given country, or globally. Researchers developed multi-stage quality function deployment with patent indicators to explore critical technologies from the perspectives of both customer and technical requirements in the context of Korean robot technologies and mobile phone communication technology (Sohn and Ju, 2015; Wang and Chow, 2016). The former paper proposed hierarchical structure with three house-of-quality (HOQ) stages which ultimately enables the development of Korean robot business models, while the latter study stressed on introducing and demonstrating patent quality weightings of patent age and mathematical technology attractiveness in the measurement of the importance of technologies.

However, considering the eyewear integration of IoT is quite new technology, and thus, so has difficulty reflecting customer needs from existing QFD approach. Moreover, extremely limited patent quality information can be captured from latest and very few patent samples. Therefore, this paper adjusts and enhances the method of generating information to recognize and describe customers' expectations specifically. Furthermore, we integrate patent quantity and proper quality indicators simultaneously to evaluate the attractiveness of the technology development. This proposed methodology can explore prospective technologies of IoT based eyewear applications and identify active countries and key actors through patent portfolio analysis.

3.1. Research architecture

This study seeks to improve the credibility of previous research

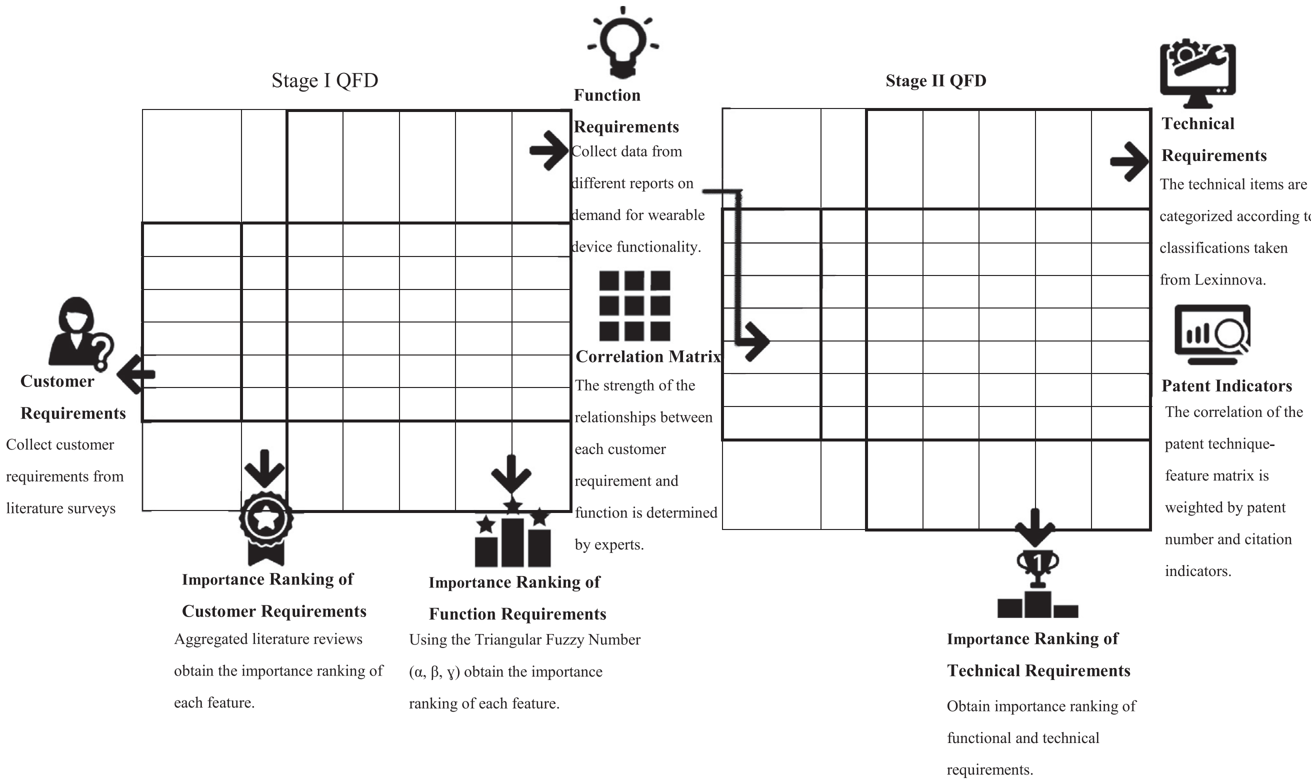

Fig. 3. Two-stage QFD research framework.

findings regarding eyewear customer demand and function demand. First, we use the QFD method to rank customer function requirements in order of importance. In Stage 2, we use the Thomson Innovation Database to collect relevant patents and apply the QFD method to identify potential IoT applications that can meet key eyewear customer needs. Finally, by using Innography, a patent search and intellectual property analytics software, to make patent map analysis with 122 sample patent documents. Furthermore, technology intelligence and commercial implications are explored. Then we create visualizations of the research results to provide a valuable reference for industry management. The research framework is shown as Fig. 2.

3.2. Two-stage QFD research framework

Two-stage QFD research framework is shown as Fig. 3. In the first QFD stage, the left side is a listing of the voice of the customer (Whats) and the ceiling of the house contains the technical descriptors (Hows) (Lampa and Mazur, 1996). Due to that the customer has a relatively low impression of current eyewear and technology integration, we sourced and used customer demands of wearable device to represent the left column "What" from relevant domestic and international reports. After conducting a review of the literature on IoT features in wearable devices, the findings were used to form the top row "How" of HOQ. The relationships between customer requirements and technical descriptors (What-How matrix) were completed through interviews with experts, the data from which were first processed using triangular fuzzy methods. The resulting data were defuzzified and then used in the stage two calculations.

In the second QFD stage, the list of functions (hows) in the first stage QFD becomes the list of "whats" in the second stage, and the list of techniques (hows) is summarized from the literature. The correlation matrix is the patent technique-feature (T-F) matrix weighted by patent indicators. (Sohn and Ju, 2015; Wang and Chow, 2016). As to the top row "How" of HOQ, we categorized the eyewear technologies based on classifications from the Lexinnova patent consultancy. The technology-function matrix (T-F matrix) was seeded with Thomson Innovation patent data for functions and technologies. Thomson Innovation (TI) database is a source for global patent data, scientific literature, business information, and news content. The TI database summarizes and rewrites the whole patent document into briefs based on "advantage," "usage," and "novelty." The correlation in the patent technique–function matrix presents classified patents and citations to indicate IoT technologies with development potential to satisfy eyewear customer requirements. The two-stage QFD method is summarized as follows:

3.2.1. First Stage QFD

In the first stage QFD, customer requirements are translated to functions. This stage consists of six steps: summarizing, and ranking customer requirements, summarizing functions, building the relationship matrix, calculating the importance of functions, and defuzzification. In the summarizing and ranking customer requirements step, the list of customer requirements ("whats") is summarized from the literature. This study collects data from five different reports on demand for wearable device functionality, and sorted the individual demands into a list ranked by importance. Top 10 customer requirements for wearable device functionality are clarified.

From the literature, this study organized the wearable device IoT functions. These functions are placed in the top row ("How") of the matrix. We then fill in the What-How matrix based on the results of expert interviews. In the building relationship matrix step, the strength of the relationships (correlation level) between each customer requirement and function is determined by two experts who are involved in a project of service design for an optical chain from the Institute for Information Industry. After the correlation level is decided, we then transformed correlation level into fuzzy numbers based on fuzzy number transformation as shown in Table 1. For example, if experts identify there is very high correlation level, the value of 0, 1, 2 will be put in the three columns for each feature (HOW). In the calculating the

Table 2
IoT three level technology analysis.

Level 1	Level 2	Level 3
Networking	Wired	Communication protocol
		Resource management
		Multiplexing methods
		Topology management
	Wireless	Resource management
		Topology management
		Communication protocol
		Multiplexing methods
		Radio frequency protocols
		Baseband processing
Computing	Algorithm	Routing algorithm
		Image processing
		Character recognition
	Encryption	Error correction
		Data security
		Data encryption
	Memory management	Information retrieval
Infrastructure	Control system	–
	Power management	–
	Hardware	Circuit
		Sensor
Miscellaneous patents	Applications	Home automation
		Transportation
		Home security
		E-commerce
		HealthCare
		Entertainment
		Alarm systems
	Measurement/Testing	–
	Others	–

importance of function step, the importance of each feature is calculated by the following equation:

$$TI_j = \sum_{i=1}^{n} RI_i {}^* C_{ij} \tag{1}$$

where TI_j represents the importance of the jth function (function in the second stage QFD), RI_i represents the importance of the ith customer requirement (feature in the second stage QFD), and C_{ij} represents the correlation between the ith customer requirement (feature in the second stage QFD) and the jth function feature (function in the second stage QFD). The higher value of TI_j means that the jth function feature is more important in the customer requirement perspective. In the first stage QFD, all values are transformed into fuzzy numbers, so the calculations should follow fuzzy arithmetical operations (Chen and Chen, 2003; Wang and Chow, 2016). The fuzzy importance of each feature is calculated using the following equations:

$$\alpha(TI_j) = \sum_{i=1}^{n} \alpha(RI_i)^* \alpha(C_{ij}) \tag{2}$$

$$\beta(TI_j) = \sum_{i=1}^{n} \beta(RI_i)^* \beta(C_{ij}) \tag{3}$$

$$\gamma(TI_j) = \sum_{i=1}^{n} \gamma(RI_i)^* \gamma(C_{ij}) \tag{4}$$

where α, β, γ represent the α, β, γ value of the fuzzy number. Finally, to rank the importance and input data into the second stage QFD, we defuzzify the importance of customer requirements, the importance of function and the correlation matrix. We use the gravity method to defuzzify each fuzzy number, which are calculated using the following equations:

$$\mathrm{CVE}(\mathrm{X}) = [\alpha(\mathrm{X}) + \beta(\mathrm{X}) + \gamma(\mathrm{X})]/3 \tag{5}$$

where X represents the fuzzy number, and CVE(X) represents the crisp value of X after defuzzification.

Table 3
Technique-feature (T-F) matrix weighting.

Weighting of total patent count	$1 - \dfrac{\text{Total patent count}}{\text{Total patent count} + \text{total patent citations}}$
Weighting of total patent citations	$1 - \dfrac{\text{Total patent citations}}{\text{Total patent count} + \text{total patent citations}}$

The first stage QFD transforms the importance of customer requirements into the importance of function, and the importance of function is then transformed into the importance of techniques by the second stage QFD.

3.2.2. Second stage QFD

In this stage, functions are transformed into techniques based on the correlation matrix in the first stage QFD. Furthermore, we introduce the patent citation indicator to adjust the importance of the techniques to evaluate the attractiveness of a particular technical development. This stage includes six steps: inputting the function importance (whats), summarizing technologies (hows), building the correlation matrix, calculating importance of techniques, calculating the patent citation indicator and identifying key technologies. The importance of each function is calculated in the first stage QFD. The list of functions (hows) in the first stage QFD becomes the list of “whats” in the second stage, and the list of techniques (hows) is summarized from the literature from classifications for wearable technologies taken from the Lexinnova patent consultancy.

In “Internet of Things, Patent Landscape Analysis” (LexInnova, 2015), a US-based patent analysis consultancy, divides the Internet of Things into three levels. As shown in Table 2, Level 2 covers the application domain of Level 1, while Level 3 is the functional characteristics of Level 2. In this study, features and technologies of IoT applications need to be clarified in the second stage QFD. The technical items are categorized according to classifications taken from the above Level 3 of Lexinnova, and items not relevant to eyewear devices will be discarded from ranking.

The correlation matrix is the patent technique-feature (T-F) matrix weighted by patent number and citation indicators. The patent search strategy is that the IoT-related wearable device functions obtained from the stage one QFD were used as conditions for searching the TI database in titles, abstracts and claims. In order to avoid the irrelevant patents, search results are limited to “eyeglasses”, and “contact lenses” phases. Patents published after May 31st, 2016 are disregarded. The final search results are used to build the correlation matrix and patent map analysis.

After classifying patents, the calculation of each correlation can be measured by the weighted patent indicators (Sohn and Ju, 2015; Wang and Chow, 2016). The optimal weight setting can be adjusted on the basis of users' priority in the different applications in general. This study uses patent number and citation indicators and evaluates them equally. In order to avoid bias from the relative values, the calculation of weight are set based on their values and can be represented as following Table 3. That is to say, if the total patent number is much bigger than the total citations, the weight of patent number will be relative lower.

Finally, the research results present a visualization of key patented technologies for functions to meet important customer needs, providing insight for future innovation and development.

4. Result

4.1. Customer requirements and features in first stage QFD

Six steps include summarizing and ranking customer requirements, summarizing functions, building the relationship matrix, calculating the importance of functions, and defuzzification were implemented as

Table 4
The first stage QFD.

	Feature (HOW)	Importance of the Whats			Rank of the Whats	Eye state detection			Eye disease detection			Non-eye disease detection			Light sensing			Distance sensing		
Customer requirement (WHAT)						F1			F2			F3			F4			F5		
Improved exercise performance	C1	8	9	10	1	0	1	2	0	1	2	0	1	2	0	1	2	0	1	2
Regular health updates	C2	7	8	9	2	6	7	8	8	9	10	8	9	10	0	1	2	0	1	2
Entertainment	C3	4	5	6	3	0	1	2	0	1	2	0	1	2	0	1	2	0	1	2
Message reminder	C4	2	3	4	4	6	7	8	0	1	2	0	1	2	0	1	2	0	1	2
Control of other devices	C5	2	3	4	5	0	1	2	0	1	2	0	1	2	6	7	8	4	5	6
Productivity tools	C6	1	2	3	6	0	1	2	0	1	2	0	1	2	0	1	2	0	1	2
Identity verification	C7	1	2	3	7	0	1	2	0	1	2	0	1	2	0	1	2	0	1	2
Safety	C8	1	2	3	8	8	9	10	6	7	8	6	7	8	4	5	6	4	5	6
Internet browsing	C9	1	2	3	9	0	1	2	0	1	2	0	1	2	0	1	2	0	1	2
Remote control	C10	0	1	2	10	0	1	2	0	1	2	0	1	2	0	1	2	0	1	2
Importance of the HOWs						62	119	196	62	113	184	62	113	184	16	63	130	12	57	122
						125.67			119.67			119.67			69.67			63.67		
Rank of the HOWs						3			4			4			9			10		

	Temperature sensing			Balance sensing			Motion tracking			Identity verification			Message reminder		
Customer requirement (WHAT)	F6			F7			F8			F9			F10		
Improved exercise performance	0	1	2	0	1	2	8	9	10	0	1	2	0	1	2
Regular health updates	4	5	6	0	1	2	0	1	2	0	1	2	0	1	2
Entertainment	0	1	2	0	1	2	0	1	2	0	1	2	6	7	8
Message reminder	0	1	2	0	1	2	2	3	4	0	1	2	8	9	10
Control of other devices	0	1	2	0	1	2	6	7	8	0	1	2	8	9	10
Productivity tools	6	7	8	8	9	10	6	7	8	0	1	2	4	5	6
Identity verification	0	1	2	0	1	2	0	1	2	8	9	10	0	1	2
Safety	0	1	2	6	7	8	0	1	2	6	7	8	0	1	2
Internet browsing	0	1	2	0	1	2	4	5	6	0	1	2	6	7	8
Remote control	0	1	2	0	1	2	0	1	2	0	1	2	0	1	2
Importance of the HOWs	34	81	148	14	65	136	90	153	236	14	65	136	66	135	224
	87.67			71.67			159.67			71.67			141.67		
Rank of the HOWs	6			7			1			7			2		

Table 5
The second stage QFD.

	Technique (HOW)	Rank of the WHATs	Switching systems	Communication protocols	EMW/ radio waves	Access/ authentication	Connection management	Processing								Network infrastructure	
								Algorithm					Encryption		Memory manage-ment	Control systems	Power manage-ment
								Speech processing	Character recogni-tion	Bioinform-atics	Image proces-sing	Others	Data security	Error correction	Inform-ation re-trieval		
Feature (HOW)			T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15
Eye state detection	F1	8	2.84	54	9.65	0	0	17	0	2.35	14.13	29.89	0	0	40.97	8.21	6.86
Eye disease detection	F2	7	0	17.67	12.69	0	0	0	0	11.48	1.86	2.14	0	0	8.4	0.93	6.41
Non-eye disease detection	F3	7	0	37.87	20.19	0	0	0	0	5.82	0	33.47	0	0	34.61	0	14.37
Light sensing	F4	2	0	24.34	2.28	0	0	2.28	0	0	0	15.96	0	1.35	10.15	7.56	11.1
Distance sensing	F5	1	0	26.37	10.93	0.56	0	4.28	0	0	1.91	13.07	0	0	8.93	8.37	22.09
Temperature sensing	F6	5	0	10.58	2.21	0	0	0.93	0	0.93	0	1.86	0	0	5	1.86	7.79
Balance sensing	F7	4	0	7.98	0.93	0	0	0.93	0	0	1.35	5.7	0	0	1.35	0	4.65
Motion tracking	F8	10	0	32.85	26.1	0.93	2.14	25.68	0	24.38	0	4.33	0	0	30.36	3.84	5.19
Identity verification	F9	4	0.93	30.37	4.42	28.51	1.28	0.93	1.35	21.49	0	10.95	19.63	0	29.37	8.32	19.28
Message reminder	F10	9	1.07	15.07	5.35	0.93	0	2.79	0	0	3.49	8.93	0	0	2.79	1.86	8.14
Adjusted of importance of HOWs			36.1	1566.3	664.5	132.3	26.5	438.8	5.4	474.3	164.8	733.0	78.5	2.7	1134.7	193.4	504.5
Rank of the HOWs			26	1	6	22	20	11	30	10	19	5	24	31	4	18	9

	Network infrastructure							Miscellaneous patents								
	Sensors	Circuits						Applications								
		Accelerometer/ gyroscope	Input/output interfaces	Camera/ optics	Communication systems	Display systems	Others	Medical devices	Heart rate	Temperature	Respiration	Movement	Eyewear	E-commerce	Alarm systems	Enterta-inment
Feature (HOW)	T16	T17	T18	T19	T20	T21	T22	T23	T24	T25	T26	T27	T28	T29	T30	T31
Eye state detection	54	6.68	1.14	8.98	0	4.98	19.77	1.28	1.28	1.28	0	0	54	0	21.58	0
Eye disease detection	17.67	0	0	1.86	0	0	2.91	14.88	0	0	0	0	17.67	0	0	0
Non-eye disease detection	37.87	0	0	0	0	0	2.35	37.87	0	0	0	0	37.87	0	0	0
Light sensing	24.34	0.93	0	1.35	0.93	0	6.45	2.05	0	0	0	0	24.34	0	6.51	0
Distance sensing	26.37	2.42	0.56	1.91	4.93	0.56	0.93	0	0	1.49	0	1.86	26.37	0	25.44	0
Temperature sensing	10.58	0.93	0	1.28	0	0.93	0	1.28	2.21	9.65	0	0	10.58	0	1.86	0
Balance sensing	7.98	7.98	0	2.28	0.93	0	0.93	1.14	0	0.93	0	0.93	7.98	0	2.79	0
Motion tracking	32.85	24.38	0	0	0	3.98	0	23.82	25.17	23.82	23.82	31.64	32.85	0	23.82	0
Identity verification	30.37	0.93	3.35	0	0	2.21	16.49	0	0	0	0	0.93	30.37	2.21	0	17.5
Message reminder	15.07	2.79	0.93	3.49	2.14	0.93	0	0	0	1.86	0	0	15.07	0	15.07	0
Adjusted of importance of HOWs	1566.3	366.9	31.5	136.4	29.8	102.1	278.5	632.8	273.0	318.6	238.2	325.7	1566.3	8.8	605.4	70.0
Rank of the HOWs	1	12	27	21	28	23	15	7	16	14	17	13	1	29	8	25

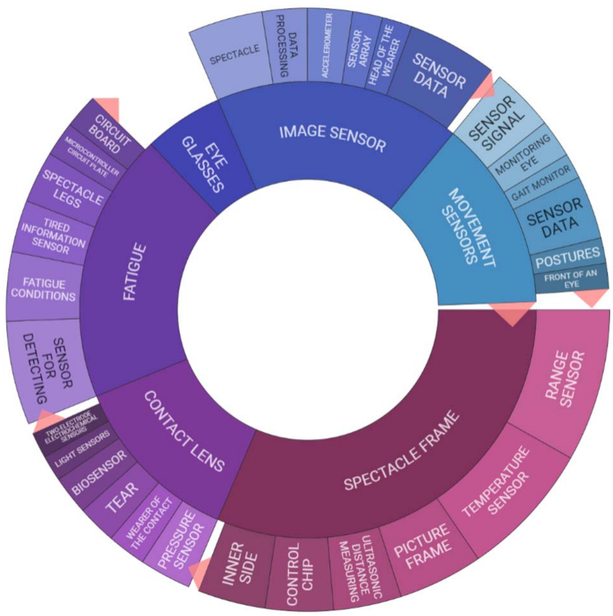

Fig. 4. Patent portfolio of "eyewear, communications protocols and sensors" technologies.

follows. In the summarizing and ranking customer requirements, this study collects five different reports on customer requirements for wearable devices. These requirements are then sorted by importance with the frequency and ranks (Institute for Information Industry, 2015; Tencent, 2015; National Experimental Institute, 2015; ImpactLab 2013; China Internet Watch; 2012). The ten most important "What" items are as follows: More effective movement (C1), Regular health updates (C2), Entertainment (C3), Message reminder (C4), Control of other devices (C5), Productivity tools (C6), Identify verification (C7), Safety features (C8), Internet browsing (C9), and Remote control (C10).

From the literature, this study organized the wearable device IoT functions. These functions are placed in the top row ("How") of the matrix. IoT development function items retrieved from the literature review include: Eye state detection (F1) Detection of eye disease (F2), Detection of non-eye disease (F3), Light sensing (F4), Distance sensing (F5), Temperature sensing (F6), Balance detection (F7), Motion tracking (F8), Identity verification (F9), and Message reminder (F10). We then filled in the What-How matrix based on the results of expert interviews. The correlation between each customer requirement and each feature is based on expert interview results. Experts assigned each cell a value from 1 (weak correlation) to 10 (strong correlation). These points were then transformed into fuzzy numbers. Using the fuzzy QDF and defuzzification, we obtained the importance ranking of each feature. In order, the five most important features are Motion tracking (F8), Message reminder (F10), Eye state detection (F1), Eye disease detection (F2) and Non-eye disease detection (F3) (see Table 4). Unsurprisingly customer requirements related to Eye state detection (F1), Eye disease detection (F2) and Non-eye disease detection (F3) are rated higher than most of others.

4.2. Features and technologies in second stage QFD

Following defuzzification, the importance of the various functions are used as the stage-two QFD "What" items to sort the technical requirements by importance. The technical items were categorized according to classifications taken from Lexinnova, and items not relevant to eyewear devices were discarded, leaving a total of 31 technology items to rank. The patent T-F matrix is weighted by patent number and citation indicators. By integrating patent quantity and proper quality indicators simultaneously, we can evaluate the attractiveness of the IoT based eyewear technologies.

According to the search strategy, there are ten functions identified from the stage one QFD and they are used as conditions for searching the Thomson Innovation database for titles, abstracts and claims for records preceding May 31, 2016. The search results produced 199 patent documents. After retrieving eyeglasses and contact lenses related patents, the final patent samples are 122 patent documents. These 122 patents were used for the calculation of each correlation of the T-F matrix and patent map analysis.

The value of each cell of the correlation matrix was decided by the patent number and citations belonging to the corresponding technology and function. According to the calculation of weight as shown as Table 3, patent citations were found to outnumber patents by over 0.93 to 0.07. Thus patent number was weighted at 0.93, and patent citations were weighted at 0.07. The totals were presented as scores as shown in Table 5. The 10 most important technology items were as follows: Eyewear (T28), Communication protocols (T2), Sensors (T16), Memory management (T13), Other (Algorithm) (T10), EMW/Radio waves (T3), Medical devices (T23), Alarm systems (T30), Power management (T15) and Bioinformatics (T8).

4.3. Technology intelligence of key IoT based eyewear technologies

From the result of the first stage QFD, the five most important features are Motion tracking, Message reminder, Eye state detection, Eye disease detection and Non-eye disease detection. After transforming functions into techniques and considering the attractiveness of a particular technical development in the second stage QFD, the 3 most important IoT based eyewear technologies are Eyewear, Communication protocols, and Sensors. By making patent map analysis with 122 sample patent documents, further technology intelligence is explored.

Innography, a patent search and intellectual property analytics software, is used to illustrate the following "eyewear, communications protocols and sensors" related patent maps. The applications and developments in the field of "eyewear, communications protocols and sensors" as shown in the Fig. 4.

These three categories cover all patent documents in the present study and interpret the overall distribution and development. Fig. 5 shows the application and development status of eyewear, communications protocols and sensors by countries. The results show that China emphasizes research related to eyewear, while the US, EU and Canada focus on contact lenses. In terms of functional applications, the US and EU show similar technology layouts, with focuses on eye tracking, user authentication, and gait and motion sensors, while China places a particular emphasis on fatigue detection.

Fig. 6 shows the global distribution of corporate patents for "eyewear, communications protocols and sensors". From the results, Alphabet, Hang Jin Ind, and Ophtimalia more focus on the development of smart contact lenses, with Alphabet patents covering Image Sensors and Fatigue Sensors, while Ophtimalia focuses on sensors to detect changes in Intraocular Pressure. Sony's technology coverage is relatively broader, including Image Sensors, Motion Sensors, User Authentication, and Display Units.

5. Discussion

The results show that smart eyewear mostly rely on control chips embedded within the eyeglass frame, with applications including distance detection, temperature sensing, ultrasonic distance measurement, image sensing and eye fatigue detection. Smart contact lenses are mostly used for electrochemical sensing, light sensing, biosensing and tear monitoring applications. Electrochemical sensors are used to monitor the user's biometric responses. Light sensors are used to detect light reflected from the iris for identity verification. Biological sensors and tear monitoring are used to detect glucose concentrations in tears.

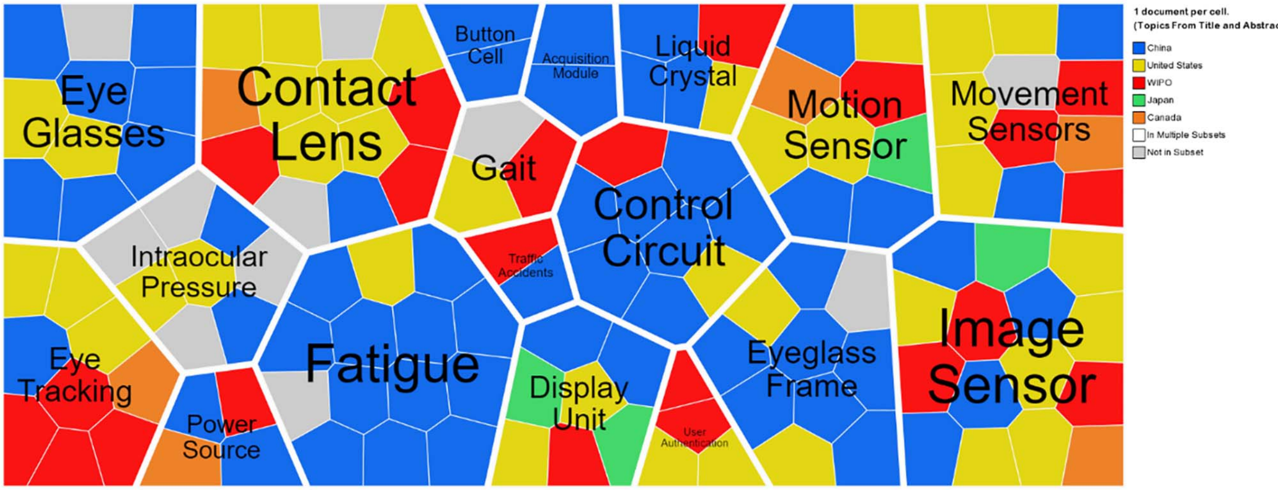

Fig. 5. Application and development status of “eyewear, communications protocols and sensors” by countries.

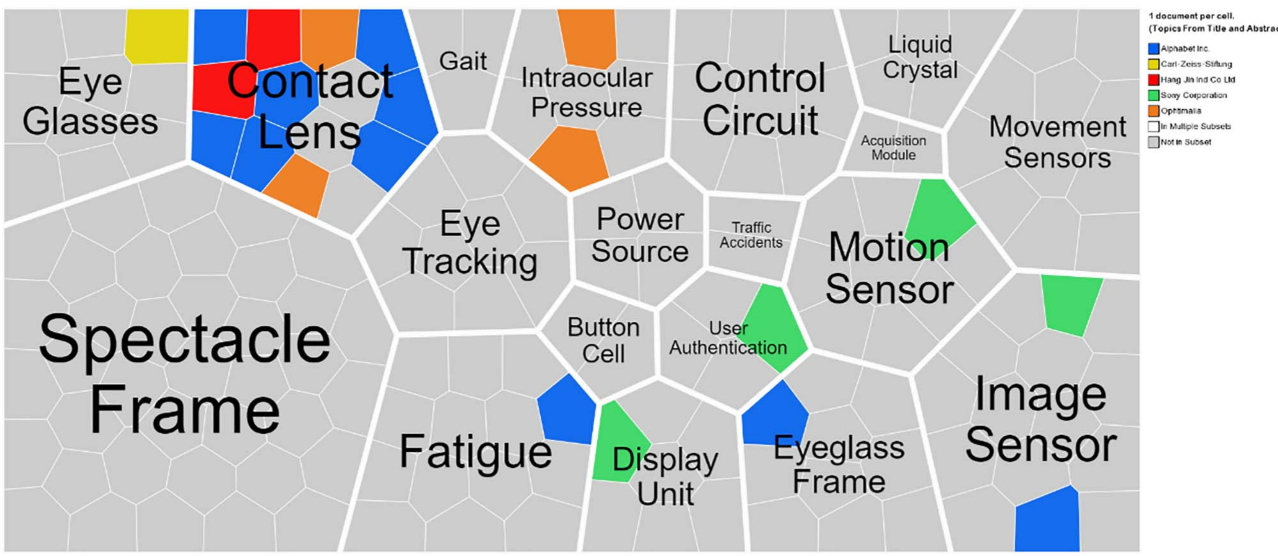

Fig. 6. Application of “eyewear, communications protocols and sensors” by companies.

Based on these descriptions, the technology being incorporated into contact lenses focuses on the development of wearable physiological monitors. Sensors involved include motion sensors, image sensors and fatigue sensors. Motion sensors are primarily used to track and record the user's eye movements. Image sensors are used mainly to identify and monitor the subject of the user's visual attention for marketing purposes. Eye fatigue detection is used monitor the degree of eye fatigue in drivers, thus reducing the incidence of traffic accidents.

Our research findings show that embedding these micron-scale sensors directly into contact lenses to monitor user physiological data can satisfy customer demand and is considered as emerging technology. This interesting finding perfectly supports that the development of microelectromechanical systems (MEMS) has driven the rapid development of smart eyewear and micron-scale sensors. In addition to providing an integrated actuator and electronic component, MEMS allow for the further miniaturization of mechanical components, enabling the development of micron-scale sensors (Ciuti et al., 2015). Therefore, commercialization of these contact lenses are springing up all over the world.

For example, Sensimed, a Swiss startup, has embedded a wireless ocular telemetry sensor (OTS) in contact lenses, using MEMS to measure intraocular pressure changes resulting from changes to eye curvature (Mansouri and Shaarawy, 2011). The collected data is transmitted wirelessly to help monitor intraocular pressure in glaucoma patients. The US Food and Drug Administration (FDA) has approved contact lenses developed by Senismed that provides 24-hour monitoring of intraocular pressure (IOP) in glaucoma patients. These smart contact lenses are currently being commercialized by Triggerfish. Wireless ocular telemetry MEMS sensors are embedded in the contact lenses to measure curvature change resulting from changes to intraocular pressure (Mansouri & Shaarawy, 2011). This data is collected for wireless transmission and monitoring, thus allowing for interventions which can delay deterioration. This IOP patent distribution coverage is similar to that of companies including Ophtimalia and Itar Medical, and academic research institutions such as the University of Dundee (Scotland) and National Taiwan University.

MEMS sensors are mainly used to effectively monitor changes to physical parameters to help prevent and manage specific diseases (Ciuti et al., 2015). Google, in cooperation with pharmaceutical giant Novartis, is integrating its sensing technologies into contact lenses to monitor changes in blood glucose in diabetic patients, and is currently seeking FDA approval. (Official Google Blog, 2014).

6. Conclusion

After implementing this two-stage QFD based patent analysis, the result showed that the 3 most important technology items which can satisfy customer demand are as follows: Eyewear (T28), Communication Protocols (T2), and Sensors (T16). The contribution of this research identifies embedding micron-scale sensors directly into contact lenses to monitor user physiological data can satisfy customer demand and is considered as emerging technology in the smart eyewear industry. The findings of this research support that commercialization of these smart contact lenses are springing up all over the world.

Based upon the results of this smart eyewear exploration, our future work intends to investigate deeply such commercialization of smart contact lenses and explore whether and how these commercialization can apply in other smart wearables. However, qualified and experienced experts in smart eyewear field are quite rare in this study. We recognize the justice and objectivity of the QFD What-How matrix based on the results of expert interviews can be adequately enhanced by inviting more experts in the following work.

As to the patent portfolio by countries, China is the world's largest eyewear market, and holds the largest number of patents related to smart eyewear. However, the patent holders are largely fragmented, with many associated with academic research institutions. Thus, though China has a large number of patents, they have a relatively low citation rate and many of the patents are relatively weak. In contrast, US patents are heavily cited, particularly for patents related to eye state tracking, eye disease sensing, non-eye disease sensing, light sensing, motion tracking, and user authentication. China has potential for development in the fields of distance sensing, temperature sensing and message reminders. From the current patent distribution, the US and EU focus on eye movement tracking, motion tracking, and user authentication, while China's emphasis is on eye fatigue detection, distance sensing and radio frequency technologies. Visualizations of overall research results can benefit eyewear-related patent holders, eyewear manufacturers and smart wearable devices manufacturers to build their patent portfolio strategies on the basis of regional or country considerations.

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