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A User-based Model for the Quality of Experience of the Internet of Things

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Highlights

- We developed a predictive model for QoE in the IoT.
- It is a user experience model of IoT, conceptualizing QoE and highlighting relationships with other factors.
- We demonstrate future IoT service categories through a heuristic quality assessment tool from a user-centered perspective.

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A User-based Model for the Quality of Experience of the Internet of Things

Abstract

The exponential development of the Internet of Things (IoT) makes it essential to cater to the quality expectations of end users. Quality of experience (QoE) can become the guiding paradigm for managing quality provisions and application designs in the IoT. This study examines the relationship between consumer experiences, the quality perception of IoT, and subsequently develops a conceptual model for QoE in personal informatics. Using an ethnographic observation, the study first characterizes the quality of service (QoS) and subjective evaluations to compare QoS with QoE. Then, a user survey is conducted to identify user behavior factors in personal informatics. Finally, a user experience model is proposed, conceptualizing QoE specific to personal informatics and highlighting its relationships with other factors. The model establishes a foundation for IoT service categories through a heuristic quality assessment tool from a user-centered perspective. The results overall provide the groundwork for developing future IoT services with QoE requirements and for dimensioning the underlying network provisioning infrastructures, particularly with regard to wearable technologies.

Keywords: quality of experience, quality of service, user experience, personal informatics, Internet of Things, quality measurement, human-centered design

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1. Introduction

A user-based model for the quality of experience of the Internet of Things

The Internet of Things (IoT) has already set in motion the idea of a fourth industrial revolution, with repercussions across a wide business spectrum. People's lives, their workplace productivity, and consumption patterns will all change dramatically. A string of new businesses will appear, expanding Internet pipes, analyzing reams of data, and creating new things yet to be imagined. The drastic increase in the development of IoT services makes it even more important that service providers measure user satisfaction levels as this will help them to identify and address areas in need of improvement. The shutdown of Google Glass suggests the importance of user experience (UX) and quality received by users. Despite the increasing need for an objective measurement of service quality, no agreement has as of yet been reached on how UX should be conceptualized or measured (Chun, Lee, & Kim, 2012). The improvement of user satisfaction in technologies has long been a major area of research (Turel & Serenko, 2006). Despite numerous attempts to understand UX, studies have focused on measuring user satisfaction indices for entire industry sectors—the American Customer Satisfaction Index (Fornell et al., 1996), for example—or they have focused on technical performance and thus neglected user value such as the quality of service (QoS). The telecommunications sector has relied on QoS as a measurement of overall performance, but its quantitative measurements considered only technical network performance (Li & Rong, 2015). Few studies have explored the quality factors affecting UX and satisfaction or sought to develop strategies for quality improvement through a user-centered approach.

As smart wearable technologies such as IoT become more complicated and compound, a conventional QoS scheme and satisfaction approach shows limitations, as both neglect the end-

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users' perspective. Although a few studies have proposed QoS evaluation models for IoT applications (e.g., Kilkki, 2008), a sparse number has attempted to apply the QoE evaluation to IoT applications. In information systems (IS), the QoE evaluates how end users subjectively perceive the quality of an application or a service. Being user-centric, it provides a more holistic understanding of the system's influence factors than technology-centric measures such as the QoS (Shin, 2015). In evaluating IoT from a user-centric perspective, it is important to balance QoE and QoS: IoT is enabled by technological features, and thus, a technical evaluation of QoS cannot be lightly treated; at the same time, services on the IoT have been used and experienced by end users, implying QoE's subjective nature, which needs focus. As the IoT consists of infrastructure and high-end services, it is important to integrate QoS and QoE appropriately. The key is how to correlate technical-level QoS with that of users. How to integrate QoS and QoE from a user-centric perspective and how to establish effective frames considering both QoS and QoE become as critical as the development of the IoT itself.

Although efforts have been made to map user behavior relative to technical network characteristics and QoS (Shaikh, Fiedler, & Collange, 2010), research on QoE and QoS has been isolated and fragmentary; their relation remains unclear, particularly in emerging technologies. The unsuccessful Google Glass case demonstrated that although technical QoS is excellent and proven, users' QoE remained unproven. Zhu, Heynderickx, and Redi (2015) argue for the need to integrate the two areas by developing a user-focused performance measurement for services in the user dimension. It is imperative to develop reliable and usable methods of determining accurate measures of UX/satisfaction with future information communication technology (ICT) services. Beyond superficial behavior or simple satisfaction, it is critical to see how users perceive quality and what kinds of experience they have with smart services.

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In this light, the goal of this study is to develop a conceptual QoE model suitable for the emerging IoT services field. It explores a sustainable framework for evaluating personal informatics by investigating what should be quantified, monitored, and analyzed to characterize, evaluate, and manage services offered through the IoT. Three research questions guide this study:

RQ1. What is the personal informatics UX in terms of motivations and quality?

RQ2. What are the factors of QoE and what are the relationships among them in personal informatics?

RQ3. How can QoE be measured from a human-centered approach as opposed to a technology-centered one?

The framework resulting from these RQs opens avenues for systematic modeling and an analytical methodology for evaluating personal informatics, surpassing the QoS evaluation advances achieved during the past two decades. This study contributes to the literature in three ways. First, its QoE model advances UX research by identifying key variables and the structural relations among them. As IoT develops rapidly, the traditional notions of QoS and UX must be changed to reflect the heterogeneous and complex nature of user preferences. Amid the growing demand for effective QoE predictions and monitoring, QoE analyses of emerging technologies and new transmission networks are lacking. QoE is especially important for advanced networks as the huge amount of traffic has exerted great pressure on resource-limited bandwidths. User-based designs for wireless systems grounded on a QoE index will enable a more effective usage of available resources.

Second, the results should prove valuable for industry practitioners engaged in IoT user satisfaction measurement as they are facing the increasing development of IoT-specific factors and satisfaction indicators while having to make vital decisions based on them. As more personal

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and business applications migrate to the IoT, quality becomes an important differentiator among providers. The QoE issue should attract a great deal of attention in the ICT sector, where UX is now considered more important than the traditional technology-centric QoS perspective (Kilkki, 2008). The new metric based on subjective and objective analyses in this study provides useful insights, particularly in disentangling possible sources of consumer satisfaction variations (and related variables) in wearable services.

Third, although this study focuses on the IoT in a Korean context, the findings probably have wide generalizability across different countries and populations. Korea is known for having the globally fastest broadband Internet connections and one of the world's most active telecom markets. Korea's hyper-connected technological infrastructure, its active users, dynamic markets, and innovative industry make it the perfect test-bed environment for new technology development and user testing. The country also becomes a general test field for emerging IT worldwide. How IoT is accepted, diffused, and successful in such a dynamic market can have valuable implications for other countries. Based on the challenges and opportunities gleaned from the case of Korean IoT, practical suggestions can be drawn for other countries regarding future IoT projects. These suggestions can also be generalized to fit wider international contexts.

Finally, this study provides guidelines concerning interface designs for personal informatics. IoT devices are unique in their focus on interfaces and interactions, allowing them to sense and actuate the human world. One challenge for IoT, as computers become increasingly invisible and less dependent on interface complexities, is to reduce the importance of interfaces and focus more on usable devices. By zooming in on the QoE model, this study offers service designers practical methods of characterizing user perceptions within a human-centered approach and technology-oriented guidelines for leading product development designed to improve QoS in

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advance of full-fledged rollouts.

2. Literature Review

2.1. Theory of human behaviors with technologies

The foundational theories for the research model are the theory of reasoned action (TRA) and the theory of planned behavior (TPB). The TRA posits that individual behavior is driven by behavioral intentions, which are a function of an individual's attitude toward a behavior and subjective norms surrounding the performance of the behavior (Fishbein & Ajzen, 1975). In his later work, Ajzen (1991) updates the TRA and introduces a new TPB by adding a new component—perceived behavioral control. The TPB covers volitional behaviors (the cognitive process by which an individual decides on and commits to a particular course of action) for predicting behavioral intention and actual behavior.

The combined framework of both the TRA and TPB has been proven to be a solid tool for explaining human behavior and it is thus well aligned with the QoE model. The rise in convergence content on the Internet has renewed interest in quality evaluations. The focus of the new concept of "evaluation" is on the user's perceived quality, unlike in classic network-centered approaches, such as QoS. Evaluating quality is heavily involved with attitude formation and change. The integrated TRA and TPB frame helps to track dynamic changes of users' attitudes and behaviors by closely linking beliefs and actions.

According to Ajzen's TPB (Ajzen, 1991), an attitude about a behavior is defined as an individual's positive or negative feelings about performing it. This is determined through an evaluation of one's beliefs regarding the consequences arising from a behavior and an evaluation of the desirability of the consequences. The overall attitude can be assessed as the sum of the

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individual desirability assessments of all the behavior's—once performed—expected consequences.

Because of the numerous factors that can affect human–IoT interaction, what is considered a positive experience for users is very likely to differ among services. Thus, the most important task in measuring an IoT service's QoE is to define a customer's desired experience in relation to the service. The TRA and TPB are good tools to tap into users' embedded attitudes and complicated motivations (both intrinsic and extrinsic). Quality (system, service, and content), satisfaction, attitude (coolness and affordance), and customer intention together form a causal chain that the combined TRA/TPB frame can effectively delve into. The user-focused measure of QoE is conveniently consonant with the frame. Both the TRA and TPB have been widely employed in user research to predict and explain attitude formation and to predict behaviors. Given the wide applicability of the TPB in emerging technologies, the general causalities found in it are expected to apply to IoT. In particular, the relationship between attitudes and intentions in personal informatics with the IoT has been confirmed (e.g., Li & Rong, 2015). The attitude-intention link can be a starting point for understanding user behavior of the quantified self (QS).

2.2. IoT and the quality of experience: data processing dissolving into behavior

Personal informatics systems are becoming increasingly prevalent as ubiquitous computing has become deeply embedded in people's lives. Personal informatics, often interchangeably called "QS," refers to technologies that help people collect, monitor, and display information about our daily activities through intelligent devices, services, and systems. Through QS, people record and monitor their own target behavior, including subjective information (e.g.,

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a problem, situation, symptom, or a disruption that symptoms may produce, as well as inner thoughts or feelings) and objective information (e.g., the frequency or intensity of a behavior).

Although the proliferation of personal informatics makes collecting personal data easier, how to help people engage with these systems and how consumers evaluate quality remain open questions. The emergence of personal informatics has renewed interest in quality evaluations. The focus of a new “evaluation” concept is on the user’s perceived quality, unlike in classic network-centered approaches, such as QoS. Over the years, QoS, the overall performance of a telephony or telecom network measured in terms such as error rate, bit rate, throughput, transmission delay, availability, and jitter, has been touted as technological requirements for most services. Although important, QoS has an exclusively inward orientation in its examination of network performance. Most service providers are thus shifting their focus from QoS to QoE, a largely outward-oriented user-focused measure (Li & Rong, 2015).

QoE is the overall acceptability of an application or service as perceived subjectively by the end user (Shin, 2015; Lauhari & Connelly, 2012). Especially Lauhari and Connelly (2012) focus on the entire service experience; it is thus a more holistic evaluation than the more narrowly focused UX because QoE assesses consumer expectations, feelings, perceptions, cognition, and satisfaction about a particular product, service, or application (Deng et al., 2010). QoE can act as a useful complement to UX. Despite its popularity, the UX concept has been neither well defined nor understood (Shin, 2015). As technological services become increasingly complex and as more service deliveries occur through advanced systems, the simple notion of UX as “usability” must be redefined. Although QoE expands this horizon, most QoE approaches have been based on analyses of the media’s technical properties; it is important to estimate user satisfaction, and QoE depends on multiple factors beyond those properties.

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3. Research Model and Hypotheses

3.1. Factors influencing QoE

A preliminary qualitative inquiry through focus groups and brainstorming along with a literature review was conducted. Based on this, a series of possible factors influencing QoE could be identified, namely satisfaction, involvement, affordance, coolness, enjoyment, and hedonicity, which are largely consistent and consonant with previous studies such as those by Zhu et al. (2015) and Gao and Bai (2014). Perceived quality included system, service, and content quality, as derived from validated IS and HCI and telecom research. Quality, satisfaction, attitude (coolness and affordance), and customer intention form a causal chain of relationships. A high level of customer satisfaction leads to higher coolness and affordances, which provide strong cues for the IoT.

3.2. Content quality

Content quality is defined here as the relevance, reliability, and timeliness of knowledge provided by IoT services. The term "content quality" has been used interchangeably with "information quality" because numerous studies have shown it to be a determinant of utility and ease of use (DeLone & McLean, 2003). Many research efforts have focused on developing content quality as a discrete determinant of quality, and content-quality variables were identified as useful predictors for ease of use and usefulness (Kuo, Wu, & Deng, 2009; Lin & Lu, 2000).

As IoT systems have become sufficiently complex to include various contents, numerous studies have employed perceived content quality in lieu of perceived information quality (Agboma & Liotta, 2010; Ghasemaghaei & Hassanein, 2015). For example, Cheong and Park (2005) applied perceived content quality to the acceptance model of mobile Internet. Their factor analyses found content quality to be a valid predictor; it was thus determined to be a significant

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factor in the adoption of that technology. Thus, users' perceptions of IoT utility seem determined by the quality of mobile content because they heavily consume important content through their IoT.

In addition, a number of studies have found a significant relation between quality and hedonic-related factors, such as enjoyment and fun. For instance, IoT technologies add a hedonic aspect to the technology use experience because they are increasingly used not only for utilitarian but also for sheer pleasurable purposes (Chun et al., 2012). As numerous studies have demonstrated that perceived hedonicity is influenced by quality factors (e.g., Deng et al., 2010), this study hypothesizes that the evaluation of hedonic attributes of the IoT is a direct antecedent of content which has a positive impact on perceived value because better content produces a more enjoyable UX. Thus, the following is proposed:

H1: Content quality has a positive effect on the utility of the IoT.

H2: Content quality has a positive effect on the hedonicity of the IoT.

3.3. System quality

System quality is the user evaluation of system performance when delivering information and meeting user needs (Yoo & Kim, 2015; Shin, 2009). The high quality of a system leads to people's satisfaction and adoption (Bernardo, Marimon, & Alonso-Almeida, 2012). Numerous investigations have found that system quality had a positive significant relationship with user satisfaction (Kuo et al., 2009; Landrum et al., 2008; Wu & Wang, 2006). System quality also plays a key role in the fundamental operations of and user satisfaction with the IoT. As an advanced system, the IoT has been strongly influenced by system quality. It is activated by operating systems that manage both its hardware and software resources. These operating systems determine system quality, which is important in an IOT context. Consumers are

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reluctant to use the IoT when they experience frequent response delays, disconnections, lack of access, or poor security (Shin, 2014; Suki, 2012). It can be stated that both system quality and user perceptions of it are equally important.

DeLone and McLean (2003) examined the relationship between system quality and user satisfaction, incorporating perceived usefulness as a measure of user satisfaction and perceived ease of use, self-appraised usefulness, and information quality as determinants of user satisfaction. They found that system quality affected the extent to which the system was able to deliver benefits by means of mediational relationships through usage intentions and user satisfaction constructs.

Interestingly, system quality may have a positive effect on the enjoyment of the IoT. The convenience of the system influences user enjoyment: the more robust the system, the higher the pleasure. It is thus possible to infer a correlation between system quality and perceived enjoyment. For example, Park, Zo, Ciganek, and Lim (2011) found that system quality had a positive influence on perceived usefulness and enjoyment. Chen (2010) also discovered that user-perceived system quality was significantly associated with the perceived usefulness of e-learning systems. It is likely that as perceived usefulness increases, perceived hedonicity also elevates as individuals experience feelings of reward. Hau et al. (2012) depict the significant effects of the perceived enjoyment of system quality in mobile services. We thus propose the following:

H3: System quality has a positive effect on the utility of the IoT.

H4: System quality has a positive effect on the hedonicity of the IoT.

3.4. Service quality

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Service quality is the assessment of how well a delivered service conforms to users' expectations (see To & Ho, 2016). When delivered through a system, the service is directly interfacing with users and its quality is critical for both adoption and diffusion. In fact, service is closely related with other performance forms and user values. Hsu, Yen, and Chung (2015) argue that service quality, in conjunction with system and content quality, significantly affects a system's post-implementation success in terms of user satisfaction. Similarly, Akter, D'Ambra, and Ray (2013) discussed the relationships among service quality, perceived value, and customer satisfaction in mobile health services. The quality of the IoT is particularly important as most applications are provided through some form of service. With the high levels of automation involved, assuring service quality is critical to the success of IoT services. Responsiveness, reliability, and assurance have been considered critical in the IoT as the services are offered across platforms and operated in diverse contexts. Several recent studies have applied these elements to the mobile sector as service quality has become increasingly important in mobile services (Aghdale & Faghani, 2012; Samen, Akroush, & Abu-Lail, 2013). Research results have consistently shown that perceived service quality is a critical factor in users' evaluation of satisfaction. Bernardo et al. (2012) show that e-service quality played a critical role in producing the perceived value of functional and hedonic quality. We thus propose the following:

H5: Service quality has a positive effect on the utilitarian value of the IoT.

H6: Service quality has a positive effect on the hedonic value of the IoT.

3.5. Users' perceived value: utilitarian and hedonic value

It is widely accepted that users evaluate ICT services along both utilitarian and hedonic dimensions (Bernardo et al., 2012). Although traditional ICT systems are mostly work-related and thus utilitarian, hedonic dimensions have become increasingly vital in the design and

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adoption of smart technologies (Chun et al., 2012; Shin et al., 2016). This study proposes that perceived utilitarian performance and hedonic motivation are two primary evaluative dimensions of IoT services. Perceived utilitarian and hedonic qualities are derived from the user acceptance model (Bernardo et al., 2012) and subsequent studies (Shin, 2014, 2015). From the viewpoint of satisfaction as an evaluative outcome (Deng et al., 2010), it is suggested that evaluations of smart services' utilitarian and hedonic performances are direct antecedents of satisfaction. We thus propose the following:

H7: Utilitarian performance has a positive effect on satisfaction with the IoT.

H8: Hedonic value has a positive effect on satisfaction with the IoT.

3.6. QoE: satisfaction, coolness, affordance, and user behavior

As reported in research such as Fornell et al. (1996), user satisfaction directly/indirectly influences user behaviors such as purchasing behavior and intention to use. Although user satisfaction has become a topic of great interest to human–computer interaction (HCI) and marketing researchers alike, its relation to psychological factors has been widely debated as UX becomes heterogeneous and new cognitive factors such as coolness and affordance emerge. An increasing emphasis is being placed on the coolness aspects of technology because users feel "cool" when given newer, innovative technological products such as curved displays, smartwatches, and smartglasses (Kim, Shin, & Park, 2015). These cool devices invoke conscious acknowledgment of the technology's "hipness" by triggering the coolness heuristic with its novelty and innovativeness, which ultimately produces positive user perceptions and experiences. In their study on the concept of coolness, Sundar, Tamul, and Wu (2014) theorized that it is a socially constructed multidimensional user-based judgment consisting of four factors: attractiveness, originality, subcultural appeal, and utility.

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Along with coolness, affordance has also become an important factor in HCI. An affordance is a relation between an object or an environment and an organism that, through a collection of stimuli, affords the opportunity for that organism to perform an action (Norman, 1990). Sundar and Limperos (2013) argue that affordances provide cues to media users, which then trigger mental shortcuts about the characteristics of the content they consume. As they propose affordance as a new gratification for new media, it can be a new UX for smart technologies. The "affordance" concept is particularly important in the IoT because the interface between it and users is nonlinear and unstructured (Karanam et al., 2014). Affordable interfaces and interactions facilitate certain user behaviors. The following hypotheses are thus proposed:

H9: User satisfaction has a positive effect on the coolness of the IoT.

H10: User satisfaction has a positive effect on the affordance of the IoT.

H11: Coolness has a positive effect on users' quality experience about the IoT.

H12: Affordance has a positive effect on users' quality experience about the IoT.

User factors may also influence the adoption and usage process (Shin, 2012). In this research, they include age, gender, and prior experience, which are tested as moderating effects (Figure 1).

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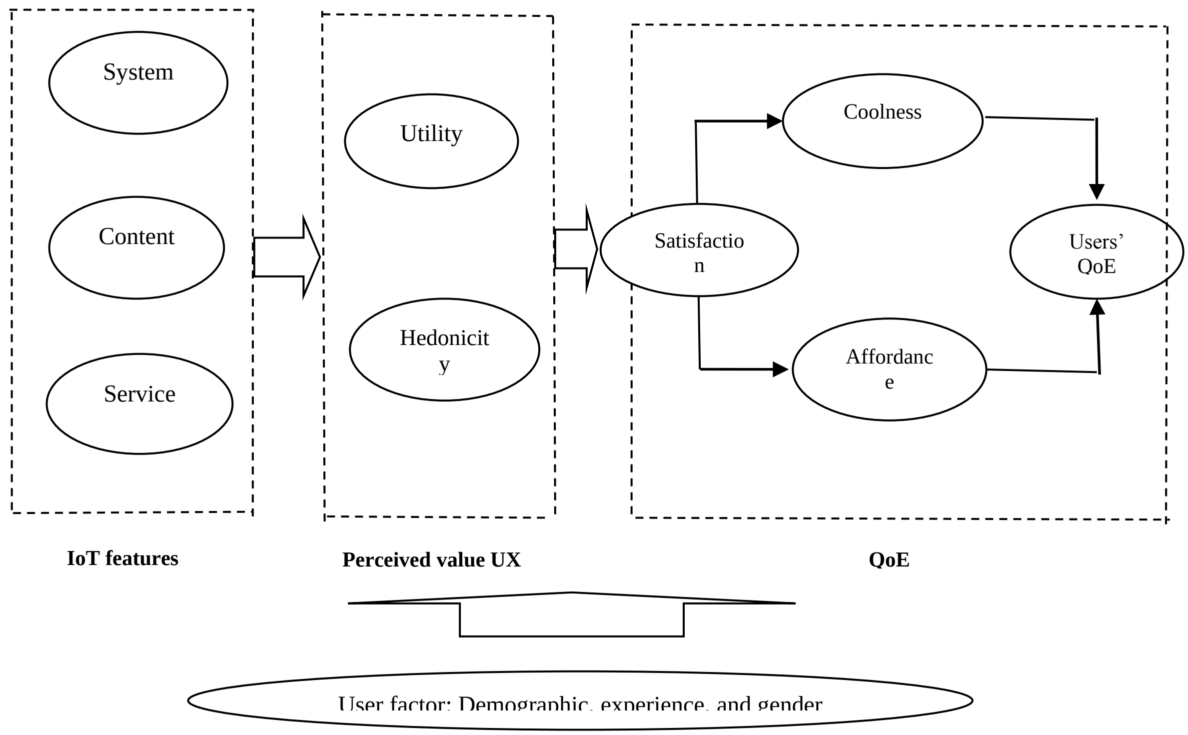

Figure 1. QoE model for personal informatics

4. Study Design

An in-depth assessment of QoE from the user's perspective requires that various methods are used to measure personal informatics' QoE. This study utilizes a combination of qualitative and quantitative methods. As defined in the ITU-T recommendation BT 500 (2014), QoE is the subjective user assessment of services. Thus, users' opinions and experiences are essential; the qualitative method is an effective way of collecting such data. Moreover, the IoT is a relatively new technology; qualitative data are helpful to understand the overall picture of the personal informatics' QoE. Qualitative data were collected through ethnographic interviews with participants carefully recruited by a professional survey firm. The goal of the ethnographic interview in developing technologies is to understand users in their real environments and—

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based on this—build personas and scenarios. Ethnographic interviews were designed to understand and specify the context of use and to grasp user requirements. The initially selected participants were carefully tested and reselected. Twenty participants were dropped in the preliminary selection. A total of 95 participants ultimately partook in the participant observation. The subjects were given a wearable band, which is a smartwatch that displays data on health, walking distance, and activities. The wristbands were specially redesigned to track the participants' activities, allowing us to follow users' physical activity, steps taken, and energy burned. This information was integrated into an online community and phone application, allowing researchers to track the data and aggregate them on a daily basis. The observation lasted two weeks and the returned logs were analyzed. During this monitoring process, the participants were required to use a QoS parameter scale composed of nine parameters (see Table 1). We used the mean opinion score (ITU, 2010), an ordinal scale assessing quality on a five-point scale from one (worst) to five (best).

Table 1.

IoT architecture and QoS parameters

Architecture	Components	QoS parameters	QoE factors
Application layer	Web service, cloud service, information processing	Accuracy, availability, stability	Service, content, hedonicity, coolness, affordance
Network layer	Internet, private network, extended network	Transmission time, storage capacity, reliability	System, utility
Sensing layer	RFID, sensor, two-dimension code, smart device	Functionality, normative, robustness	Utility, coolness

(Source: Li & Rong, 2015)

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After the observation, the participants were required to respond to an online survey and received a small amount of money. The NVivo software was used to analyze the qualitative data as they could not be easily reduced to numerical data. For the quantitative data, a structured survey questionnaire was constructed, which was administered to respondents who had used or experienced any kind of IoT service. A total of 490 valid questionnaires were collected and analyzed with a partial least squares (PLSs) tool.

4.1. Measurement development

Unlike other studies, which normally draw measurements from previously validated measurements, this study develops its measurements referencing ethnographic inquiries to users. Ethnographic methods produced a conceptual mapping with keywords and the latter are matched to previously validated variables taken from previous research. Keywords such as “useful,” “helpful,” and “enjoyable” are compared to measures of utilitarian and hedonic value adapted from Bernardo et al. (2012) and Shin (2014). Keywords such as “happy” and “delight” are linked to measures of satisfaction and usage derived from Gao and Bai (2014) and Roca et al. (2006). Coolness and affordances are expressed through various terms and wordings. Those categories are broadly fitted to measures developed by Sundar et al. (2014) and Kim et al. (2015). Keywords such as “service,” “system,” and “contents” are matched to measurements developed chiefly in IS research such as Fornell et al. (1996), Parasuraman et al.’s (1988) SERVQUAL, and Shin (2009), respectively. The scales used in this study consisted of 24 items, with three items per factor. A pilot test was conducted prior to analysis. Participants indicated their agreement with a set of statements using a 10-point scale.

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A survey questionnaire was developed in conjunction with outside consultants and experts (professors, researchers, and industry experts). A Delphi method was used to take the expert opinions using a structured communication technique based on a systematic, interactive forecasting method. The panel answered questionnaires in two or three rounds. A pretest was carried out to determine both test–retest and construct reliability indices before conducting the fieldwork. Forty current users with an interest in the IoT and M2M services participated in the two pretests at 2-week intervals.

4.2. Instrument validity and reliability

This study used the two-step approach to PLS modeling as suggested by Anderson and Gerbing (1988). It first assessed convergent validity and reliability. Construct validity confirms the extent to which the results are compatible with and parallel to theoretical or conceptual values. Convergent validity was determined by composite reliability (CR), factor loadings, and the average variance extracted (AVE). As shown in Table 2, all constructs had CR values of more than .88, which is higher than the recommended value of .7. The AVE measures the variance captured by the indicators relative to the measurement error and should be greater than .5 to justify the usage of the construct. The AVEs were in the range of .84 to .92. The results showed that the convergent validity allowed the use of the criteria and that the instrument based on the constructs was suitable for the data collection.

Table 2.

Convergent validity and internal consistency reliability

	Items	Factor loadings	CR	Cronbach's alpha
COQ	CQ1	.873		.868
	CQ2	.832	.93	

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	CQ3	.832		
	SEQ1	.813		
SEQ	SEQ2	.945	.92	.893
	SEQ3	.916		
	SYQ1	.855		
SYQ	SYQ2	.901	.90	.901
	SYQ3	.834		
	PU1	.795		
UTI	PU2	.864	.88	.891
	PU3	.808		
	PH1	.697		
HED	PH2	.695	.89	.925
	PH3	.892		
	CS1	.877		
COO	CS2	.835	.94	.912
	CS3	.832		
	CC1	.824		
AFF	CC2	.945	.91	.923
	CC3	.913		
	CL1	.855		
SAT	CL2	.822	.90	.891
	CL3	.825		

-CR = (square of the summation of the factor loadings)/{(square of the summation of the factor loadings) + (square of the summation of the error variances)}
-COQ: Content Quality, SYQ: System Quality, SEQ: Service Quality, HDE: Hedonicity, UTI: Utility, SAT: Satisfaction, COO: Coolness, AFF: Affordance

The discriminant validity of the measures was assessed by examining the correlations between the measures of potentially overlapping constructs. As shown in Table 3, the squared correlations for each construct were lower than the AVE from the indicators measuring that construct, indicating adequate discriminant validity. Overall, the measurement model demonstrated adequate convergent validity and discriminant validity.

Table 3.

Correlation and Q^2 value

	COQ	SEQ	SYQ	UTI	HED	COO	AFF	ATT	Q^2 value
COQ	.85								.013
SEQ	.311*	.87							.046
SYQ	.410**	.39	.87						.135
UTI	.339*	.310*	.426**	.93					.344
HED	.459**	.399*	.415**	.305*	.90				.431

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COO	.381*	.471**	.422**	.321*	.422*	.84			.004
AFF	.416**	.423**	.311*	.394**	.332*	.581*	.91		.092
ATT	.311*	.331*	.391*	.311*	.48**	.402**	.310*	0.88	.183

*p < .05; **p < .01

Finally, when one's model consists of latent variables with high levels of internal consistency, to be consistent with the causal–predictive goal of PLS, a greater focus should be placed on the model's predictive relevance. The extent to which this prediction exercise is successful can be measured by the Q^2 statistic. This study selected the omission distance (*D*) = 8. $Q^2 > 0$ indicates predictive relevance; Table 3 shows the Q^2 values. The reliability and validity of the PLS was reconfirmed using Chin's method (1998), in which a two-step process was proposed: assessments of (1) the outer and (2) the inner models.

4.3. Survey administration

The survey took place after the qualitative participant observation (Table 4). To acquire good-quality data, the survey was administered by a professional marketing firm specializing in survey development, data collection, analysis, and reporting. The company possesses a robust panel of data related to various customers. The topic of IoT necessitated hiring a specialized company. To control for country-specific effects, only residents of South Korea were surveyed. Surveying this sample population yielded statistical results generalizable to the entire Korean user population as all respondents had used wearable devices for at least 3 months; this is sufficient for establishing reliable perceptions and opinions of the service. In addition, this sample is representative of the country's entire user population, based on a comparison of the demographic data. A chi-squared test for goodness of fit showed that market shares did not differ significantly between our sample and the Korean market at the 1% level (chi-squared test statistic of 9.83 with three degrees of freedom, for which the *p*-value was 1.4%).

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Table 4.

Characteristics of respondents (N = 490)

Age	*n*	UX	*n*	Education	N	Gender	*n*
Under 20	86	Less than 6 months	17	High school or less	90	Female	245
21–30	190	1–6 months	101	College	315	Male	245
31–40	184	7–12 months	120	Graduate school or higher	73	Chi-square	9.11
Over 41	30	Over 1 year	252	Others	12	*p*-value	1.0

5. Findings

5.1. Qualitative data analysis

Qualitative assessment builds on user attitude, opinions, and comments. The qualitative data were analyzed for codes and themes using NVivo. Based on the pilot interview, we created a coding scheme composed of nine keywords: “system,” “service,” “content,” “satisfaction,” “intention,” “usefulness,” “enjoyment,” “affordance,” and “coolness.” All collected responses were fitted into the scheme. The classification was performed by four coders. The concordance was checked using Cohen’s kappa test, which shows that the coding results achieved .89 (a high degree of agreement between the coders). Table 5 shows selected responses.

Table 5.

Selected comments from respondents

	Selected responses
Content	“[IoT] *provides various information and services”* *“The services and information I can get are valuable”* “[IoT] *provides the information and services that I need”*
Service	*“The wearable device provides very reliable service”* *“The speed of the wearable is fast and secure”* “[IoT] *is safe and transparent to use”*
System	*“I think the RFID technologies work fine”* *“The underlying technologies are solid and established”*

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	"The operating system of the wearable devices was fast and interoperable" *"The sensors support the overall functions of IoT"*
Utility	*"Using IoT service is very useful to my life in general"* *"Having the wearable is helpful to improve my performance in general"* *"Utilizing the IoT is helpful in enhancing the effectiveness of my life in general"* *"The IoT provides very useful service and information to me"*
Hedonic	*"I really enjoy playing with it" "I found the device fun and delightful"* *"It is really fun and exciting to have it"* *"While using it, I enjoy a new and entertaining experience"*
Coolness	*"This IoT is stylish" "This device is hot" "This wearable is sexy and hip"* *"People who use this device are unique" "This IoT makes people who use it different from other people" "This IoT is original and cool"*
Affordance	*"I like the idea of using this IoT. I feel inclined to wearables"* *"I think this technology makes my life more interesting"* *"I have a generally favorable attitude toward using this* [IoT]. *Overall, using this device is beneficial and helpful"*
Intention	*"Definitely I will use it in the future" "It is my favorite in coming back"* *"I intend to use it as much as possible"* *"I will strongly recommend that others use wearables"*

The keywords were counted and tracked using a semantic network for the analysis of which the software was helpful. Based on the results, a conceptual model was created (Figure 2).

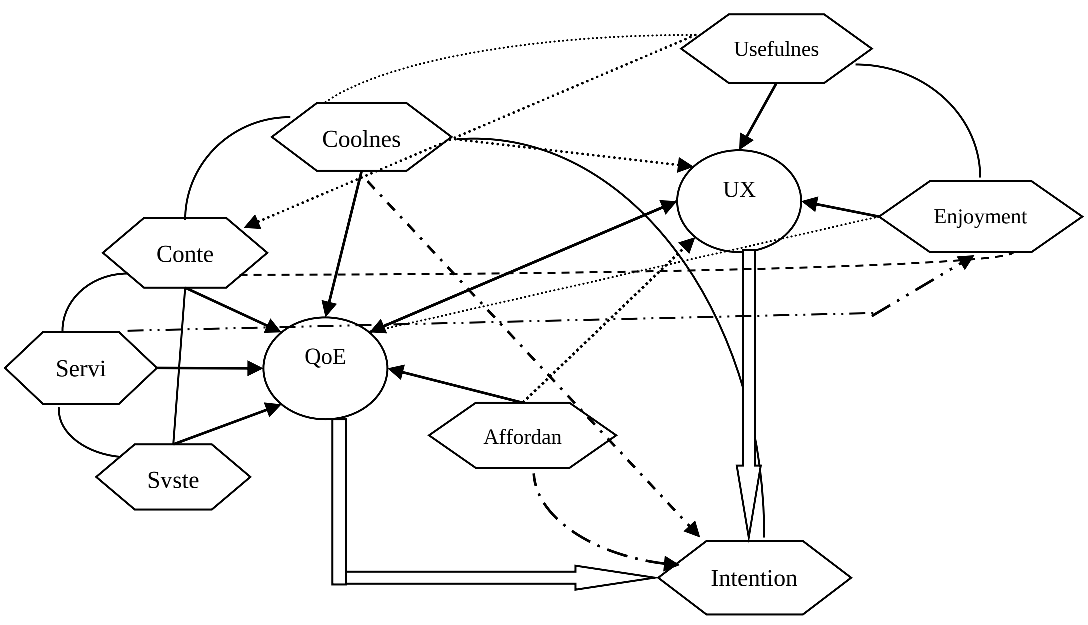

Figure 2. Conceptual model from qualitative data

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The conceptual model shows that QoE is clearly different from UX as their various features are accounted for by different factors. The qualitative data show a heuristic link between QoE and quality factors (content, service, and system) and between UX usefulness and enjoyment. Although UX is characterized by these two traditionally recognized factors, people view QoE alongside quality aspects. Moreover, two new factors (coolness and affordance) are positioned between QoE and UX, but people tend to see them closer to the former. Together, QoE and UX affect intention, whereas coolness and affordance influence intention more directly. The conceptual model implies more complicated relations among the factors. It is worthwhile to further examine them by quantitative analyses.

Next, QoS and QoE were compared in three steps. First, the QoS parameters (speed, packet loss, jitter, delay, bandwidth, and burst) of wearable devices were measured and recorded. Then, QoS parameters were normalized using a QoE evaluation scheme (see Table 6). Then, these numbers were compared through a mean opinion score obtained from users' self-reported data. These scores (Likert 1–5) were computed for each QoS parameter.

Then, following the method used by Li and Rong (2015), principal component analysis was conducted to compare QoS and QoE, whereby two principal components were obtained. These are as follows:

$$QoS = 0.57Z_1 + 0.53Z_2 + 0.49Z_3 + 0.29Z_4 + 0.51Z_5 + 0.32Z_6$$
$$QoE = 0.58Z_1 + 0.23Z_2 + 0.46Z_3 + 0.21Z_4 + 0.54Z_5 + 0.14Z_6$$

(Z_1: delay, Z_2: jitter, Z_3: loss, Z_4: error, Z_5: speed, Z_6: bandwidth)

The eigenvalues and contribution rates of the two principal components are shown below along with their coefficients and significance.

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Table 6.

Comparison of QoS and QoE

QoS Parameter	QoE evaluation					Factors	Quality
	1	2	3	4	5		
Packet delay	>210 ms	190–210 ms	170–190 ms	150–170 ms	< 150 ms	Application (functionality, accuracy)	Content quality
Packet jitter	>70 ms	50–70 ms	30–50 ms	10–30 ms	0–10 ms		
Packet loss	>1.4%	.9–1.5%	.4–1%	.1–0.5%	0–.1%	Sensor (availability, robustness)	Service quality
Packet error	1<	2–1	3–2	4–3	5–4		
Speed	>49%	59–50%	69–60%	79–70%	100–80%	Network (reliability, transmission, capacity)	System quality
Bandwidth	>49%	59–50%	69–60%	79–70%	100–80%		

Principal component	Eigenvalue	Contribution rate	Cumulative contribution rate	Coefficient	Principal component
QoS	3.071	61.31%	61.138%	.434	.000
QoE	1.949	38.74%	98.321%	.413	.000

The comparison shows that the evaluation scores for the QoS and QoE are very similar. Their correlation shows a general inverse proportion. The self-reported QoE score reveals that functionality has the highest QoS score (4.89), followed by availability (4.72). Overall, the participants saw the application layer as the most important QoS, followed by the sensing and network layers. This result is consonant with the normalized QoS score, where service and content displayed higher coefficients than network quality. These findings suggest that the users' evaluation of QS quality is aligned with the QoS of the IoT.

5.2. Quantitative data analysis

A PLS regression extracts principal components from different measurement variables of latent dimensions by using the data in a regression model to find relationships between independent (exogenous) and dependent (endogenous) variables.

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5.3. Mean and standard deviation

After survey data collection and compilation, mean values and standard deviations were summarized (see Table 7). The mean value shows the average level of customer evaluations. The results indicated that their expectations of quality were high: Customers liked good-quality service, content, and systems. At the same time, the mean value of complaints was also high, suggesting that they disliked some IOT aspects. All standard deviation values obtained in this survey were almost equal to 2, indicating that there were only slight differences in the evaluations.

Table 7.

Mean and standard deviation

Variable	Item	Mean value	Average of mean	SD	Std. Error Mean	Skewness	Kurtosis
	CQ1	6.599		2.4432		-.965**	1.092**
COQ	CQ2	6.428	6.521	1.9825	0.14382	-.617**	.651
	CQ3	6.536		2.2791		-.870**	1.142**
	SEQ1	6.484		2.0324		-1.171**	1.100**
SEQ	SEQ2	6.222	6.347	2.1012	0.24933	-.504**	.086
	SEQ3	6.335		2.1792		-1.142**	.356
	SYQ1	6.307		2.6805		-1.043**	.305
SYQ	SYQ2	6.310	6.239	2.0582	0.24358	-.965**	1.125**
	SYQ3	6.102		2.4524		-1.123**	.139
	PU1	5.931		2.5447		-.631**	.324
UTI	PU2	6.502	6.4096	2.3230	0.20334	-1.001*	2.847**
	PU3	6.794		2.2874		-1.478**	1.877**
	PH1	6.231		2.0581		-1.345**	2.260**
HED	PH2	5.397	5.6596	2.1015	0.16784	-1.618**	.673
	PH3	5.339		2.2655		-.618**	7.212**
	CS1	6.428		2.2114		-.871**	0.070
COO	CS2	6.212	6.4021	2.4922	0.16882	-1.170**	-.585**
	CS3	6.565		2.4421		-.508**	1.472**
	CC1	6.237		2.4525		-1.145**	1.001
AFF	CC2	6.189	6.2297	2.4235	0.24423	-1.046**	.014
	CC3	6.251		2.0904		-.965**	1.193**
SAT	CL1	6.575		2.9241		-1.124**	1.232 **
	CL2	5.337	5.7573	2.2022	0.16352	-.632**	.029

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CL3	5.359	2.0022	-.739**	.029

The standard deviation parameter refers to each item of a variable
** Skewness or kurtosis significant at the 1% level
* Skewness or kurtosis significant at the 5% level

5.4. Coefficient calculation

Using Simca-p, the coefficients for each latent variable and R^2 of the data from the survey are shown (ranging from .24 to .49). With PLS, a structural model (inner model) was used to examine the relations among the variables. The equation is as follows:

$$\xi_j = \beta_j^0 + \Sigma_{i=1, i \neq j}^{J} \beta_{ji} \xi_i + \zeta_j \quad \forall j = 1 \ldots J$$

$_j$ = constant term; $\_{ji}$ = regression coefficient; $\__j$ = residual term

Relations of manifest variables and their corresponding latent dimension: Each latent variable μ is indirectly describable by a set of manifest variables X and each relates to its respective latent variable through a simple regression:

$$Xjh = jh0 + jh.\mu jh + jh$$

μjh has a standard deviation of one.

Relations among latent variables: The model is a set of linear equations among latent variables. The overall form is as follows:

$$\mu_j = \beta_{j0} + \beta_{ji} . \mu_j + \varepsilon_j$$

Considering the formula above, the linear equations among the latent variables of the model are as shown in Table 8.

Table 8.

Model variables, parameters, and equations

Endogenous variable	Exogenous variable	Equations
UTI	COQ, SEQ, SYQ	UTI = C+β_1COQ+β_2 SEQ+β_3 SYQ+δ

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HED	COQ, SEQ, SYQ	HED = C+β_4COQ+β_5 SEQ+β_6 SYQ+δ
COO	SAT (UTI+HED)	COO = C+ β_7UTI β_8HED+δ
AFF	SAT (UTI+HED)	AFF = C+ β_9 UTI+β_{10}HED+δ
UQE	COO, AFF	UQE = C+β_{11}COO+β_{12}AFF+δ

Having identified the above equations, all the coefficients and parameters can be estimated using PLS. The hypothesized causal paths were estimated, and all 12 hypotheses were confirmed (see Table 9). The results also supported the proposed model well, verifying the key roles of quality, perceived value, and satisfaction. Customer expectations and the results for all latent variables are satisfactory, with high Q^2 and R^2 values. The results for the total effects of satisfaction on coolness and affordance were also significantly positive. The findings highlighted the significant role of perceived value in determining user satisfaction. Regarding the impact of quality on perceived value, all path coefficients were significantly positive. The strong predictive ability of quality for perceived value was evident. Perceived utility and hedonicity exhibited significant direct effects on satisfaction (H7 and H8). The impact of quality on satisfaction was generally greater than that of perceived value, in line with the notion that although value may be more important in consumers' initial purchase decisions, quality still plays an important role throughout the usage process (Fornell et al., 1996). It also supports the finding that consumer satisfaction is more quality- than value-driven. Still, given the strong impact of quality, additional paths from quality to satisfaction were tested. With three newly added paths (content quality to satisfaction, service quality to satisfaction, and system quality to satisfaction), the overall fit of the model improved, including most of the goodness of fit indices. All three paths displayed significant coefficients, implying the key role played by quality and the role of various dimensions.

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The average redundancy of the model was estimated at 0.19. The R^2 value ranged from .395 to .421, and its mean was .352. The goodness of fit index can be calculated as follows:

$$\text{GIF} = \sqrt{0.501}\ (\sqrt{\text{communality}}) \times \sqrt{0.3498}\ (\sqrt{R^2}) = 0.420$$

Because the Q^2 of every endogenous latent variable is positive, it can be concluded that all the latent variables were selected correctly, the model is valid, and the paths are reasonable.

Table 9.

PLS standardized path coefficients

Hypothesis	Path coefficient (*β*)	*P*-values	*t*-statistics	Support
H1: COQ →UTI	.49	.003	4.221***	Yes
H2: COQ → HED	.38	.040	4.093**	Yes
H3: SYQ → UTI	.27	.023	2.798**	Yes
H4: SYQ → HED	.24	.082	2.973*	Yes
H5: SEQ → UTI	.37	.044	3.201**	Yes
H6: SEQ → HED	.41	.033	3.394**	Yes
H7: UTI → SAT	.42	.042	5.491**	Yes
H8: HED → SAT	.24	.033	3.837**	Yes
H9: SAT → COO	.41	.090	3.451*	Yes
H10: SAT → AFF	.39	.002	3.316**	Yes
H11: COO →UQE	.44	.001	4.311***	Yes
H12: AFF → UQE	.48	.000	4.932***	Yes

-S.E. is an estimate of the standard error of the covariance
-All *β* are circumflex (^) beta
* $p < .05$; ** $p < .01$, *** $p < .001$

Identifying the given relations is a complex procedure in which all latent variables are involved. The equation used is as follows:

UQE (User quality experience) =
0.291COQ+0.1681SEQ+0.187SYQ+0.091UTI+0.094HED+0.132COO+1.932AFF+Constant

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The R^2 of user behavior explained about 40% of the variance with two exogenous constructs in the model (coolness and affordance). As both R^2 values (utility and hedonicity) were fairly high, the model provides potential advances in both theory and practice.

5.5. Moderating effect

To investigate the demographic moderator effects on IoT use and adoption, moderation analysis was performed using the split-sample approach (Ha et al., 2007; Serenko, Turel, & Yol, 2006), which employs the pre-established levels of a moderator unique to the study and thus not modifiable by the researchers. For example, a person's gender naturally creates two moderator levels. To identify a one for age, the dataset was divided into two sets, each representing individuals belonging to a particular generation. An analysis of the age distribution showed two major age groups: junior and senior (cutoff: 30 year old). Representatives of these generations may fundamentally differ in their characteristics, perceptions, and behaviors. Serenko et al. (2006) used 40 years of age at the day as the cutoff point and this study follows this criterion. To specify the moderator level for experience, the sample was divided into two groups, high and low experience, depending on prior experience and knowledge of the IoT.

The moderating effects of the user variables were tested by comparing the path coefficients, which were calculated using *t*-values as suggested by Chow (1960), produced for each moderator in the two groups. Table 10 shows the results of the comparisons, which reveal a number of significantly different structural relationships. Overall, there are more moderating effects in the QoE paths than the perceived values and IoT features. This illustrates the complicated role of QoE, in which users with different kinds of experiences may perceive features and values differently. The path coefficient from satisfaction to coolness/affordance for the junior group was significantly larger than that for the senior one, and it displayed

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significantly higher paths from coolness/affordance to behavior. The same effect for the high-experience group was significantly larger than that for the low-experience group. However, the other paths were not significantly affected by experience levels (e.g., utility/hedonic→satisfaction; quality→utility/hedonic). This implies that experience is more strongly related to motivational aspects than to functional factors. The more experience users have, the more likely they are to feel coolness and affordance. Moreover, as the IoT becomes easier to use, prior experience becomes less important.

The moderating results are in line with many research results, as well as with intuition. Generally, young people have a preference for cool technologies (Sundar et al., 2014) and stronger feelings for affordance than older people (Sundar & Kim, 2015). Similarly, it can be inferred that greater experience leads to diversity in coolness and affordance, which together affect the users' QoE. This supports the notions that QoE is formed primarily based on user perceptions and experiences about quality.

The behavioral factors' influences differed substantially according to the subject's age. As a factor influencing intention, coolness was more prominent among younger individuals than older ones. Interestingly, gender did not affect any of the factors in IoT service adoption or use. Although this is consistent with previous studies showing no sex differences (e.g., Shin, 2012), it contradicts the findings of Sanchez-Franco, Ramos, and Velicia (2009) who found that gender exerted a significant moderating effect on the acceptance of Internet services. This discrepancy can be explained by observing that QS is a much more advanced technology than early Internet services and that gender has little influence on the acceptance of QS. Recent studies show that there is little difference between genders in the adoption of emerging technologies as they become increasingly easier to use and more available to diverse groups of people.

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Table 10.

The results of moderate effects

Path	Gender (*t*)	Age (*t*)	Experience (*t*)
H1: COQ →UTI	1.082	1.011	1.594
H2: COQ → HED	.191	.224	1.921
H3: SYQ → UTI	.191	-.453	.422
H4: SYQ → HED	.011	.189	0.531
H5: SEQ → UTI	.312	.291	1.412
H6: SEQ → HED	.324	.4011	**3.991***
H7: UTI → SAT	.144	**3.012***	1.644
H8: HED → SAT	.053	.391	**3.431***
H9: SAT → COO	.291	**5.322****	**2.011***
H10: SAT→ AFF	.001	**4.422****	**3.221***
H11: COO → UQE	.112	**3.323***	**4.412****
H12: AFF → UQE	.024	**5.203***	**3.991***

(*$^{*}p < .05$, $^{**}p < .001$*)

Effects	Results	References
Gender	Generally, gender did not show moderating effects. Emerging technology such as IoT is gender agnostic.	Wang et al. (2009) found no moderating effect of gender on the relationship between performance expectancy and intention.
Age	Moderating effects on coolness, affordance, and satisfaction. Coolness and affordance are prevalent among young people.	Sundar et al. (2014) found moderating effects of coolness and affordance
Experience	Overall, experience affects value and satisfaction. An evolutionary technology such as the IoT becomes easier to use. Prior experience or competency becomes less important. Industry should differentiate the way they consider customers based on their level of experience.	Ilias et al. (2014) show that prior experience strengthens the relationship between performance expectancy and satisfaction, whereas it lessens the relationship between satisfaction and intentions to repurchase.

Overall, a clear pattern can be identified in the moderating effects. The most significant ones are found in the area of QoE, where they are identified in the paths of coolness and affordance (H9, H10, H11, and H12). Although other moderating effects are found in H7 and H8,

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the significance and effect levels are much higher in coolness and affordance: The moderating effects are clearer in affordance and coolness (QoE) than in utility or hedonicity (UX). Based on the clear pattern of moderating effects in QoE, it can be inferred that QoE is greatly influenced by user factors, which further implies that it is about user preferences and attitudes.

6. Discussion

The UX research using QoS models to overcome the limitations of technology-oriented measurements has its own limitations as most UX is still superficial and mechanical, focusing on external user behaviors and having been applied in the industry in an overarching manner. Little in-depth understanding of quality experience has been sought. Furthermore, there is no standardized measure for wearable computing services. Likewise, the quality literature tends to focus on nonuser issues such as design features or technical functionalities, commercial advantages, and product capabilities instead of on how users really feel about and experience the specific services. The UX index has been used for marketing and commercial purposes but has not been properly researched or put into a theory. There is an absence of studies on the IoT and related services in research on UX and customer satisfaction. To address this gap, this study proposes a QoE model to explain users' heuristics: how individuals develop quality experiences in the use of IoT services. The results increased our understanding of their IoT services' quality perceptions and clarified the implications for the development of user-based IoT services and applications. The results of the structural model tests also supported our proposed research model. Overall, it was shown that the models demonstrated good predictive powers and explained the quality index model of IoT services.

The results of this study showed that the QoE model can accurately describe the service perceptions and QoE of personal informatics users. Consistent with prior research on service

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satisfaction, the usage of QS services was found to be determined by perceptions of value and quality, which lead to user satisfaction. High user satisfaction in turn affects coolness and affordance. Highly satisfied customers demonstrate an elevated likelihood of reuse or repurchase. Furthermore, the findings confirmed the importance of perceived quality in terms of service, content, and the system to QS services and demonstrated that these qualities contribute to utilitarian and hedonic value.

This study used a novel approach to assess QoS by employing users' self-reported data and measuring cognitive perceptions of their feelings about a service rather than calculating technical performance. Interestingly, many QoS and QoE aspects correspond or are equivalent (coefficient and factor rank), implying that the former is indeed based on the user dimension and that quality is a user property that resides in user perception as well. Although quality features (i.e., content, system, and service) may have their own properties, more important is how users perceive and experience them. To improve QoS in certain technologies, the industry must not only improve technical features but also facilitate users' interactions with the technologies. In this study, coolness and affordance (where new paths in the model were established) were facilitating factors in user perceptions of the IoT quality. In other words, coolness and affordance might play an intermediary role between users and technology, increasing usability and interfaces, thus improving acceptance. Although the results could not be validated here, future studies may pursue this line of inquiry as such factors are key components in QoE, the heuristic factors of which the current research defines for personal informatics.

Based on the findings, a new conceptualization of QoE can be proposed by highlighting four ideas of quality. First, quality can be viewed from an interactive procedural aspect rather than from a static factor perspective. Most of the research on perceived quality has focused on

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discrete factors (e.g., content, service, and system), neglecting that they are processed in the user domain (e.g., how users perceive, accept, experience, and interact). The procedural view of quality highlights the dynamic nature of QoE. Furthermore, the combined qualitative and quantitative methods used in this study reveal the dynamic nature of how users' cognitions are influenced by and influence quality.

Second, in relation to the above, quality can be viewed as an in-between concept between users and technologies, playing heuristic roles. Previous research has tended to isolate device quality from perceived quality: The users' perceived quality is seen separately from the technical quality embedded in devices. The roles of heuristic factors identified here imply that quality can be a heuristic link between users and the technological domain. Quality should be seen as a combinational concept of technical quality and user-perceived quality as these are correlated and interact with each other.

Third, given the identified importance of users' perceived quality, quality can be seen as more of a user-dependent concept than a device-dependent one. The findings in this study imply that although technical features and functionalities could improve quality, how users assess, utilize, experience, and continue to use a technology determine their ultimate satisfaction, which in turn forms QoE. During this process, users take control over the technology or the device. Quality makes more sense as a user-dependent concept under the user-centered design principle.

Finally, considering the points above, quality can be taken as a multifaceted concept rather than as a linear function between factors or a unidimensional notion, encompassing many different meanings concerning the device, context, and users (Figure 3). Users judge and experience quality in various ways and diverse contexts. Thus, rather than pursuing a universally applicable QoE model, it should be seen as a relational or coevolving concept in a contextual

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sense that flexibly conjoins users, devices, and interaction. People's QoE is based on the context in which the IoT is placed; the users' demographic factors; their experience; and the quality of the content, service, and system.

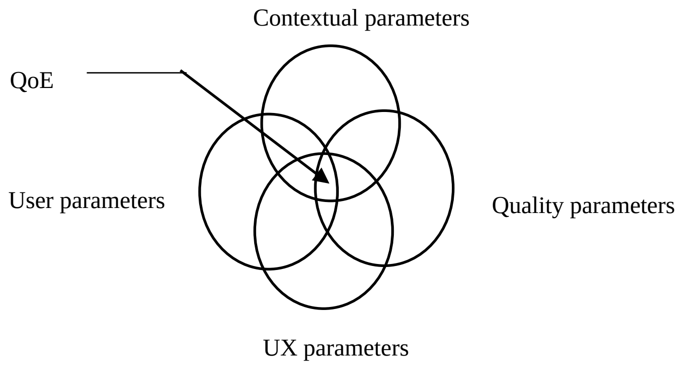

Figure 3. Compounding concept of QoE

7. Implications for Theory and Practice

7.1. Theoretical implications

This study represents a relatively new approach for evaluating the QoE for IoT applications. The empirical findings confirm that the QoE model is a worthwhile extension of the UX in the context of the IoT as it allows the effective measurement of heuristics and quality with regard to IoT services. Conventional UX and QoS approaches often fail to measure all relevant factors, or they are assessed using older and less precise methods. These limitations have prevented traditional user requirement designs from generating powerful new-generation outcomes. A primary contribution of this study is that it theoretically conceptualized the notion of quality in the IoT and established a relationship between technical quality and users' perceived assessments. As illustrated in Figure 4, quality exists fluid-like during the interaction with technology by users playing heuristic roles. The quality of experience is not limited to technology itself. It is embedded in and becomes active during the interaction between users and

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technology. For example, quality takes into account how well a service satisfies the UX expectations rather than focusing only on technical performance. In this regard, it can be stated that quality might be the result of an ongoing information-based process that embeds meaning in symbols and that it takes place within users. Taking this view one step further, quality is in the eye of the beholders. Thus, it cannot be measured by technological features or the intention of an industry because it is a subjective experience only captured by the users. It is a form of awareness, and its degree reflects the intensity of a user's cognitive, emotional, and sensory connection to both the content and the form of a technology. In light of subjective quality, one contribution of this study is that it extends engagement as a user-based dimension to new factors and conceptualizes them as a quality of experience that can significantly influence attitudes and trigger behaviors of users. Furthermore, it exists in the users' domain, so an individual's quality of experience depends on how that user accepts, experiences, and interacts with a technology.

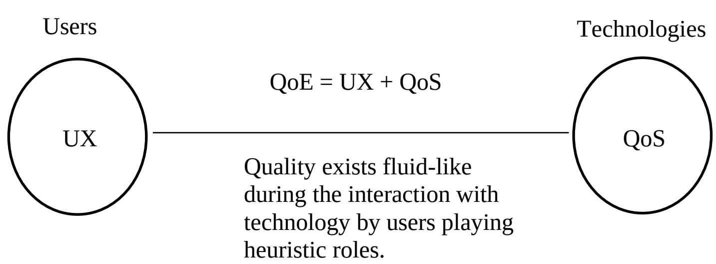

Figure 4. Quality as an in-between concept

Previous studies on user satisfaction/behaviors have often been criticized for their lack of context-specific understanding or of user perspectives (Shin, 2105; Zhu et al., 2015), which leads to satisfaction models with weak explanatory power. Incorporating IoT-specific factors and contextual considerations into a satisfaction model allows a better explanation of how the factors influence users' satisfaction and how that satisfaction, in turn, affects behavioral factors.

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Although studies in the UX and QoS literature are plentiful, few have researched the measurement and scale of IoT quality. Most research on UX has examined the impacts of perceived quality on customer intentions for services. However, these studies have neglected to adequately define “quality” (Shin, 2015). This concept in the IoT may refer to different experiences and user perceptions of it, and it is necessary to approach quality from user dimensions. The rapid development of technologies has greatly improved the QoS offered and improved users’ expectations and thus their perceived quality. Reflecting this technological evolution, it is important to treat perceived quality in a more sophisticated and user-oriented manner. This study categorized quality into three dimensions and showed that it may reside in user perception and may represent the technical performance of QoS.

Despite the enormous amount of research, UX studies have not provided a clear and genuine concept of the “user dimension” and its relations. The elements of UX and QoE remain undefined. This study employed a combinational qualitative and quantitative approach for a UX model of the individuals who actually used specific services, rather than of people who might have never experienced them. The data from the survey reflect users’ in-depth attitudes and meaningful behaviors and not just their self-reported perceptions. Our findings imply that the key elements of QoE include coolness and affordance, which play facilitating roles. Because QoE is subjective, coolness and affordance (generated by users’ subjectivity) are nicely consonant with it. Read et al. (2011) argued that coolness includes users’ beliefs about having cool stuff and doing cool things (through IoT). These aspects lead to being cool, which in turn leads users to use/reuse IoT services. Cool experiences bring joy and satisfaction; they also contribute to people’s personal motivations, which was clarified in this study.

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The aspect described in the previous paragraph implies that coolness is a core element in the UX that has not been clearly represented outside of people's minds. Individuals' technology preferences have not been reflected because something complicated and compounded with other factors; this something is about the coolness users feel about the technology. Coolness is somewhat related to and overlaps with affordance. They, at times, work together and/or mutually influence each other to affect user intentions and behaviors. Coolness is the linking mechanism between users' perceptions and behaviors, whereas affordance is the direct linking point between attitude and behavioral change. Together with affordance, coolness constitutes the QoE whereby users' quality of experience is formed through an inner mechanism. Unlike QoS, QoE resides in users, not in technologies. How users feel about and perceive their technology usage is more important than what technological functions offer to them. This is supported by the fact that QoE is greatly affected by users' demographics or contextual factors, whereas utility and hedonicity (both considered the fundamental factors of UX) are not.

Despite this finding, there is still a long way to go before we understand clearly what coolness is and how QoE is formed, sustained, and transformed. Because of its complicated and compounding nature, future studies may further delve into (1) what other QoE factors can be found in IoT and other technologies, (2) how cool experiences can be measured, and (3) how affordance can be operationalized in accordance with user intention.

7.2. Practical implications

Practical implications for the industry from these findings can be derived in terms of strategies and new models for advanced smart services (Table 11). The industry has not been sure about how to measure the quality of new services delivered through wearable computers.

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This study's findings on user modeling and quality frameworks will help the trade to prepare for more user-centered design in future services.

The practical implications for the industry can be briefly summarized. First, based on the relationships identified between consumer experience and quality perceptions of the IoT, the industry could develop a method of reflecting UX in future IoT design and development. The conceptual model of QoE in personal informatics will be helpful in devising such methods.

Second, based on the structural relationships among the QoE factors, shedding light on the heuristics of personal informatics, the industry can generate ideas for future wearable devices and identify key user behavioral factors, which can help to bridge the gap between consumers and devices.

Third, based on the findings on the relationships between QoS and QoE, the industry can develop services that balance the two. It can then generate protocols and the architecture to produce human-centered designs. One of the challenges in contemporary and future IoT is developing services with QoE requirements. This paper should offer a small but critical insight regarding human-centered design for the IoT.

Table 11.

Practical implications

RQs	Findings	Practical implications
RQ1: UX of personal informatics	- The relationships between UX and quality perception for wearable devices - The interdependence between QoS parameters and QoE values is shown - UX is more dependent on users than on technologies.	- Reflecting UX in IoT design/development - Improving quality in reference of user acceptance - Balancing QoS and QoE
RQ2: Factors and the	- A conceptual model for QoE in	- Heuristics for IoT

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relations among the factors	personal informatics - Key user behavioral factors - Quality is in the eye of beholder	- A heuristic quality assessment tool -Improving interaction
RQ3: Human-centered approach	- A gap between QoS and QoE - A user model balancing QoS and QoE - Qualitative and quantitative - Subjective and objective - Behavioral science-informed UX design can maximize benefits for all	- Protocols for human-centered design - Developing future IoT services with QoE requirements - Proactively detects network issues for faster resolution

On the basis of these implications, the industry should formulate a competitive strategy based on the QoE model to retain current customers and to enhance the management of customer relationships. Assessing QoE is now about gaining a holistic view of the entire UX spectrum beyond what operators used to focus on—network coverage and throughput to assess network performance—and no longer just a measurement of service quality at the device level.

The findings suggest that the industry should move beyond monitoring QoS and expand that focus to QoE. Whether the user enjoyed the content as a function of reliable, efficient, and secure content delivery through QS needs to be confirmed.

The potential success of the QS may be linked to the provision of diverse useful applications and enjoyable services. Personal informatics are increasingly ubiquitous and accessible. Consumers desire seamless interconnections among all kinds of devices and networks. As indicated in numerous studies, including this one, personal informatics devices represent digital connections to friends, family, and resources. This trend will be accentuated and spread globally as personal informatics continues to increase in availability. In light of this, service providers should increase the perception of availability for users.

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As the focus of this study was on the IoT, it has potential implications for the design and implementation of future Internet services. Consistent with prior research in technology acceptance, the two constructs of perceived usefulness and hedonicity continue to play major roles in user perceptions and in follow-up behavior toward products and services. From a user perspective, this represents useful service operation and a more enjoyable service through a ubiquitous seamless network, offering attractive smart service features.

As far as quality is concerned, the results of this study can be used by the QS industry to better understand users and markets to determine what quality factors should be emphasized. The findings also provide useful insights for the development of effective marketing strategies to meet customer demands and both retain and expand the user base. The finding that quality dimensions impact usage behavior through intention indicates that carriers should understand a consumer perception of quality. This can best be achieved by ensuring that such services are conducted in accordance with user expectations, namely that their contents are high quality, their services reliable, and their promises and commitments kept.

8. Limitations and Future Studies

Although the findings of this study are valid and valuable, the results should be approached with caution for several reasons. First and most importantly, the sample may not represent the whole population of QS users. The subjects were recruited only in South Korea, which may limit generalizability of the findings. Although a relatively large sample was collected and considered large enough to generalize, the question still remains whether the sample was perfectly or objectively representative to allow painting an accurate picture of the whole population.

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Future research will also have to focus on experimental testing of the model in other contexts to increase generalizability.

Second, the findings reflect only limited aspects of UXs with QS. Because personal informatics technology and its services are not yet mainstream phenomena, this research is exploratory and limited by the fact that its findings cannot be generalized to the overall experience of QS users. It is unclear whether QS represents a kind of the IoT. This study did not consider the moderating effect of other demographic characteristics such as educational level, income, or culture. Furthermore, because current QS providers are continually updating their services' contents and functions, it is difficult to follow the trail of consumer use experiences longitudinally. Such a study could have monitored the evolution of customer behavior across changing services. Instead, the circumstances of this study led to limited generalizability. In addition, the research model is only valid for the Korean QS market due to restrictions in data collection. Generalization of the model's scope would require a global data collection process for a thorough validation. Future studies could investigate a larger and more diverse cross section of the population, using stratified or quota sampling to ensure a certain distribution of demographic variables. For a generalized application of the extended model, a global data collection for validation would be required. The first step should be to test the IoT model in other countries, after which a globally accepted universal model could be developed.

IoT users evaluate their own needs and verify the relative interests, compatibility, availability, and other features when making decisions about adoption and continued usage. The fit between personal needs and product features predicts the adoption behaviors of technological innovations. Thus, future research might include the needs of users and the characteristics of innovative products, the content of media messages, and other, more specific

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dimensions to conduct a more thorough investigation of the proposed model. A time-series study measuring prior expectations and post-use evaluations of these constructs would increase the theoretical validity of the model. The extent to which this study reflects the actual phenomena of ongoing QS services must be considered with these limitations in mind. The proliferation of quality factors makes it important to develop a robust, unified, and quantifiable QoE metric. Future research can work on the development of an efficient and effective QoE framework for monitoring and analyzing QoE and other influencing parameters for future smart services.

Biography

Dr. Shin is a Full Professor at Chung-Ang University and a Distinguished Endowed Professor of the Ministry of Education in Korea. Prior to Chung-Ang University, he was a former founding Chair of the Department Interaction Science at Sungkyunkwan University. As a Director of the Interaction Science Research Center, he also served as a Principal Investigator of BK21 Plus, a national research project hosted by the Ministry of Education in Korea.

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