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Quality of Life Technologies: Experiences from the Field and the Key Research Challenges

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Abstract — Inevitably, as our basic human needs (food, housing, etc.) are assured in any developed society, the differentiation factors for our Quality of Life (QoL) relate to our greater capacity to make informed decisions across daily life activities, especially those related to our health. Availability of powerful, personalized and wearable mobile devices facilitates the provision of ubiquitous computing applications enabling the health monitoring and QoL improvement. This paper introduces the concept of QoL technologies and presents examples of currently researched mobile services for monitoring and improvement of the individual's day-to-day physical and psychological health, social interactions or environmental conditions. Furthermore, it defines the quality of service (QoS), individual's quality of experience (QoE) and inter-relation between the QoS, QoE and QoL. It summarizes the technical and trans-disciplinary aspects of the research process and challenges identified so far, and it delineates the future work areas for a successful deployment and adoption of QoL technologies.

Keywords quality of life, living lab, quality of service, quality of experience, mobile computing, mobility patterns, mobile Internet, mobile health

1 INTRODUCTION

There is a growing need for transdisciplinary efforts towards understanding fundamental theories of Quality of Life (QoL) and linking these to an understanding of complex practical problems related to day-to-day individual's QoL [1]. According to the World Health Organization (WHO) the QoL is "*individuals' perception of their position in life in the context of the culture and value systems in which they live and in relation to their goals, expectations, standards and concerns*" (1995) [2]. The WHO has defined also the assessment scale called WHOQOL, which assesses the individual's QoL across four domains, i.e., physical and psychological health, social relationships and environment, and 24 sub-domains (Figure 1). The sub-domains embrace subjective and objective aspects of life, and are being collectively exhaustive and mutually non-exclusive and potentially correlated, e.g., there is an influence of noise (i.e., environment) on the sleep and rest (i.e., physical health). Health is an aspect of the individual's life that spans across all the different QoL domains.

Since the proposal of WHO there have been many specialized QoL scales developed and evaluated for the purpose of accurately assessing individual's QoL. In this paper we employ the WHOQOL as the most generic and applicable across different variables (health states, age groups, ethnicities, professional roles of an individual, etc.).

In parallel to the above-described developments reaching back 90's, since 2000s, a phone, then a feature-phone and now a smartphone became widely available and its usage became an indispensable skill supporting our day-to-day needs for information, communication and computing while

mobile, i.e., "on the go". There exist many different applications supporting us in these needs, specifically via particular applications designed for e.g., news, video-chat or gaming.





QoL Domain	Facets incorporated within QoL domains
 Physical Health	Activities of daily living Dependence on medicinal substances and medical aids Energy and fatigue Mobility Pain and discomfort Sleep and rest Work capacity
 Psychological	Bodily image and appearance Negative feelings Positive feelings Self-esteem Spirituality/religion/personal beliefs Thinking, learning, memory and concentration
 Social relationships	Personal relationships Social support Sexual activity
 Environment	Financial resources Freedom, physical safety and security Health and social care: accessibility and quality Home environment Opportunities for acquiring new information and skills Participation in and opportunities for recreation/leisure act. Physical environment (pollution / noise / traffic / climate) Transport

Fig. 1. WHO QoL domains and sub-domains [2]

A smartphone becomes a 'prosthetic' in our daily life, being at least 50% of the time at our arms reach [3]. It is highly probable, that a smartphone (and connected to it wearables) is becoming a tool enabling us to improve substantially our health and day-to-day activities contributing to our QoL.

We define the *QoL technologies* research as a research on fundamental Information and Communication Technologies (ICT) leveraging methods, models, algorithms and services that enable identification of specific individual's needs in the QoL domains and enable subsequent ICT-based

solutions improving of the individual's QoL in these domains.

The research scope of this paper embraces particularly the technologies enabled by *mobile* communications, computing, and related fields like context-awareness, ubiquitous and pervasive computing, wireless communications, as well as privacy and security solutions. *mhealth* solutions are these leveraging the mobile technologies for provisioning of services related specifically to health.

From the research perspective the contribution of this paper lies in providing an overview on the current state of the art in the field of QoL technologies derived from analysis of several research projects conducted in last 5 years. Additionally, analysis of the dependencies between an individual's (i.e., a mobile services user) service provisions and experiences in different contexts: locations, times and personal circumstances (e.g., at leisure, under stress) and their potential relation to an improvement of this individual's QoL in different domains, is provided. Thirdly, this paper contributes to the state of the art by discussing the technical research challenges, as well as transdisciplinary ones applied to the QoL technologies, that need to be solved to for a successful deployment and adoption of these technologies.

2 QoL TECHNOLOGIES: CURRENT APPLICATION AREAS

The QoL technologies research laboratory is based at University of Geneva, Switzerland (www.qol.unige.ch). In the following paragraphs, a selection of recent (i.e., since 2010) QoL laboratory projects sponsored by the EU Ambient Assisted Living (AAL) and Swiss NSF programs, as well as a selection EU-based (ec.europa.eu) and US-based projects (nsf.gov, www.cmu.edu/qolt) is referenced in their dominant domain of application. The selection of all projects is systematic as it is based on the specific keywords ('quality of life', 'mobile computing') defined by the project investigators, yet by no means claims to be complete; the field is evolving and recent advances may not be documented yet.

2.1 Physical Health

The AAL-TraiNutri project enabled an assessment of physical activity of individuals along day-to-day activities like walking, biking, running, based on a smartphone build-in accelerometer sensor. The AAL-WayFiS focused on assessment of mobility patterns of seniors and support for their trips via a navigation service personalized for their health state (energy, pain and fatigue). The selected US projects

focus on gait assessment (NSF-1231712), balance training (NSF-1117706) or medication reminder for seniors (NSF-1111568, 1117279), physical activity encouragement for children (NSF-1439241), or routine modeling for families (NSF-1418622). Even broader, European initiatives MOVE, EYTO and OPEN research community-based practices to promote physical activity in socio-economically disadvantaged.

2.2 Psychological Health

The AAL-ANIMATE aims at services to intellectually stimulate seniors by enabling them to exchange knowledge and skills with younger generations. The AAL-MyGuardian project focuses mainly on positive feelings and self-esteem of seniors with mild cognitive impairments by enabling them to execute their plans for activities of daily living, e.g., going for shopping, while ensuring them that they will not get lost in case of an episode of a confusion. This service is also improving the QoL of the seniors' caregivers, which will not worry where the senior is, as they will be given detailed information, when needed. A more fundamental research conducted with the SNSF-PCS-OBEY project researches a computational model of the individual's perception of intimacy along daily life activities and its relation with content sharing decisions (e.g., posting a photo on Facebook). The selected US projects focus on memory assessment methods and trainings for seniors (NSF-1404333), self-esteem and positive feelings elicitation in veterans (NSF-1418523), as well as psychology-inspired robotics (NSF-1262860). The European initiatives focus on mental health promotion (MHPhands), embracing mental illness (MH-WB) and preventing suicide (EUREGENAS).

2.3 Social Interactions

The above-mentioned AAL-ANIMATE project enables social interactions between seniors and younger generations. The selected US projects focus on computational modeling of face-to-face behaviors during social interactions (NSF-1117187), social stress management including coaching (NSF-1117279), while European initiatives focus on social inclusion (CORRELATION) and social determinants of health for older populations (HealthPROelderly).

2.4 Environmental Conditions

The COPD24 project predicts pollution levels for different locations and times – across a city, potentially enabling the individual suffering from COPD to make better health decisions. UnCrowdTPG project focuses on understanding and improving the individual experience of the public transportation services in Geneva (TPG). The QoSIS.com and SNSF-MIQmodel project aims

informing to the users about the best quality mobile Internet option provided at a given location/time by a given mobile provider. The selected US projects focus on environmental determinants of mobility for wheelchair users (NSF-1406626) and European initiatives focus on air pollution (APHEKOM), EMF exposure (EFHRAN), and workplace safety (ENWHP).

2.5 Conclusive Remarks

Most of the research efforts and outcomes are now in the domains of physical health, social interactions and environmental resources of an individual; some projects focus on psychological aspects of the individual's day-to-day activities, although a newly established research domain called *affective computing* strive to fill that gap with in depth knowledge. It may be difficult to address aspects of the psychological/sociological domain due to a challenge of accurate 'operationalization' of complex domain models and theories in technologies.

The majority of the above presented projects are interdisciplinary, (inter)national collaborative projects; involving potential users of the proposed solutions spanning across different cultures and different socio-demographics. Yet, the solutions are fragmented and although most projects have a high potential to contribute to one of the QoL domains; by focusing on improvement of the day-to-day physical activity, nutrition, positive feelings, enabling social interactions or providing information about mobility; they do not approach the individual in a *holistic manner* linking the QoL aspects of these domains in a coherent manner.

However, on the other hand, an intervention in one domain is likely to influence other domains. The QoL domains are intertwined. An example is when individual would get negative feelings from use of technologies for social interaction, which may influence lower use of technologies in this and other domains, and possible even more negative feelings. In contrary, negative feelings (e.g., initiated by external events or by use of malfunctioning technologies) may stimulate the individual to use technologies for social interaction, enable to share these feelings and improve them towards positive ones.

3 QoL TECHNOLOGIES: RESEARCH CHALLENGES

Based on the overview of the projects, we define the key challenges are still undergoing basic research and which must be resolved to advance the field. We further explain the interrelation between the four QoL domains in context of the QoL technologies.

3.1 QoS, QoE, QoL Definitions & Dependencies

Research in mobile computing and communications considers a mobile service and its two important concepts – an objective, quantifiable *Quality of Service* (QoS) and a subjective, qualifiable, *Quality of Experience* (QoE). A mobile service is a data service that is delivered to (or from) a mobile device from (or to) a fixed node, i.e., application server on the Internet (i.e., in the cloud, Figure 2). The service delivery is supported by the deployment of a service infrastructure distributed over mobile and fixed nodes, in turn supported by the underlying heterogeneous network infrastructures including a wireless access network and wired network infrastructures. Wireless access network, e.g., 2.5/3/4G or WiFi enables a user the connectivity to the Internet while 'on the move'.

The QoS for a mobile service is defined as “a collective effect of service performances which determines the (objective) degree of satisfaction of a user” [4] and it embraces the service dependability (i.e., if the service is available or not) and its speed (i.e., how fast the service is provided) and accuracy (i.e., how many errors are there). The QoE is “the overall acceptability of service, as perceived subjectively (i.e., qualitatively) by the user” [5], yet there is no exact, definite definition of QoE, neither of factors influencing it [6], especially in context of QoL technologies. Current approaches indicate that the user, his/her device on which the service is provided, the service and its content are the components, which must be considered when assessing the user's QoE.

The chain of dependencies between the QoL, QoE and QoS is as follows in Figure 2. The QoS has the smallest “scope” – between the mobile device and a server. The QoS influences the QoE of a user – for example in case of the system being faulty; the user experience may drop significantly [6]. In turn, the QoE, having in its scope the perception of the user (represented in the figure by a range of emotional responses), influences the QoL of this user.

The specific dependency between QoE and QoL in mobile computing comes (at least partially) from the fact that individuals, especially in industrialized countries, rely on a growing scale on Internet and mobile services [7] to complete tasks in their day-to-day life. Namely, services are now treated as commodity and users take them for granted and rely their daily tasks and day-to-day decisions relating to their QoL, hence their QoL in a long term, on the provision of these services. We live in co-called “experience economy” [8], where providers of

services are considered to the level at which they can change the “experience” the user is perceiving.

When a (mobile) Internet service delivers high QoE the user takes it for granted and improves his/her day-to-day QoL by means of using this service to facilitate his needs for information, communication or support and make informed decisions across daily life activities [6]. When a service does not provide expected QoE, the user’s task gets negatively influenced, as well as his/her inner state changes (anxiety, stress), hence influencing his/her momentary QoL and potentially even a long term QoL, depending on the impact of the system usage on the outcome of the task.

The QoL of the individual may be influenced negatively particularly in case if this individual relies on QoL technologies to fulfill some tasks (e.g., hedonistic or utilitarian [9]) and if (1) QoE/QoS chronically fail to meet the user’s expectations and satisfy the individual’s experience, causing stress and dissatisfaction and/or (2) if the task at hand relates to a critical condition of the individual (e.g., exacerbation of symptoms while managing chronic condition), and the technologies fail to provide sufficient QoE/QoS to satisfy the individual needs (e.g., for communication) and then the individual fails to fulfill the task at hand.

In the case of (1) the long term stress related to use of technologies will influence the individual’s QoL negatively in a long term, while in the case of (2), the consequences may influence the state of the individual in a short term. In critical cases, these can be life threatening (thus influencing the individual’s QoL).

The concrete example illustrating it is as follows. Ben-Zeev et al. [10] research mobile technologies for mental health enabling the self-management for patients suffering from depression and schizophrenia. It has been observed that malfunctioning technologies (i.e., providing low QoE/QoS) experienced by the schizophrenic patients in some cases caused *exacerbation of symptoms* of the disease and hospitalization. None of such effects were observed in case of depression patients, which were much less reactive and more lethargic in their use of technologies.

Summarizing, for a given interaction of the user with QoL technologies, without the assured QoS, the user’s QoE gets influenced negatively, in turn potentially influencing the users’ QoL. Therefore, the research on QoL technologies embraces the research on QoS (i.e., objective aspects of these

technologies), as well as QoE (i.e., subjective aspects of technologies). Yet the research on QoL technologies has a larger scope than QoE/QoS, as explained in the following sections.

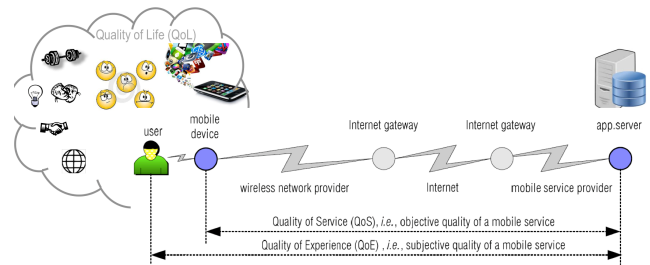


Fig. 2. QoL, QoE, QoS in a mobile service delivery

3.2 QoS for Mobile Computing: Challenges

Analyzing the research efforts we identify the following QoS-related challenges.

Mobile Connectivity – the availability of mobile Internet leveraging wireless access technologies (3G/4G/WiFi) is considered as an indispensable for a smartphone. Prediction of this availability supporting the QoS required by for a given service and management of connectivity overhead (e.g., battery) are challenging.

Speed and Accuracy – timeliness and an error probability for an algorithm/model’s output may influence the system’s dependability. Research shall investigate types of errors and model their influence on the user’s QoE.

Energy-Efficiency – device’s limited battery lifetime is a challenge and much research is put in it, including efficient access protocols, data processing and operational aspects (e.g., switching its screen OFF).

Context Sensing and Prediction – user’s location, activity, or social interaction status can be derived via the sensors embedded in the mobile device. Research focuses on context sub-sampling, abstraction levels of context (e.g., GPS vs. semantic location). Context prediction may correlate with the user’s needs for QoL technologies in this context.

3.3 QoE for Mobile Services: Challenges

Analyzing the research efforts we identify the following QoE-related challenges.

Factors Influencing QoE – The QoE is a complex concept, which needs research efforts to be accurately modeled, predicted and assured, especially for mhealth, where (non)usage of a service may influence e.g., the individual’s health

state.

Routines vs. Non-routines – a mobile service enables the user to fulfill a task in a given context. The more critical is the task, the more critical it is to assure the user's QoE. Research focuses on understanding and modeling the routine and non-routine tasks and to assure their QoE.

Context-awareness and Intelligibility – the challenge is how the user is explained with the context-based service choices and how the user can provide feedback to the system to correct its actions.

Security and Privacy, Ethics – research is needed on privacy/security mechanisms that would enable the user to be informed about what data is collected from them, by whom/why, and enable providers to be kept responsible for the data they collect and use. Ethics aspects of mobile services influencing QoL of individuals are emerging.

User Interaction Design – any mobile service has an interactive design component, i.e., an interface employing graphical (i.e., visual), auditory and kinesthetic (i.e., tactile) components, correlating with the user's QoE [11]. The research focuses on effective, usable, and intuitive interaction.

3.4 QoL Technologies: Challenges

Mobile solutions, which impacted positively QoL were mainly directed to the domains of physical or psychological health in chronic conditions so far. This was either because of the domain being impacted [12], or the fragility context of the subject population [13]. Other domains and contexts still need to be systematically investigated. Other, higher level challenges, remain open, as follows.

Iterative, User-Centric Design to Understand Relationship to Technology – QoL technologies may be at arm's reach, but unless they are already a part of individual's life, cannot be exploited to a full potential. Research shows that the more the user is integrated in the research of a technological solution; in a continuous, interactive design process the more probable is that the solution gets accepted [14]. The research focuses on user acceptance factors (e.g., technological literacy, privacy considerations) for QoL technologies, and factors influencing the individual choices, especially health [15].

Legalization/Standardization of Technology – Recently, the US Food and Drug Administration (www.fda.gov) claimed for the necessity to regulate and certificate mobile apps, especially those related

to health self-management, which requirements/provisions differ ranging from health promotion (i.e., possible "best-effort", non-evidence based) to medical practice (i.e., high-accuracy, evidence-based requirement). European Commission also recently started open dialogue on mhealth via "Green Paper" (ec.europa.eu/digital-agenda). These policy-based efforts are motivated by issues such as privacy/security, data accuracy and liability, related to a category of applications that can act as medical devices. The research of evidence for the technology to improve the QoL of an individual remains open.

QoL Technologies: User's Role – Research questions arise when considering the role of the individual using the QoL technologies, i.e., is he/she healthy individual taking preventive measures (e.g., maximizing the daily physical activity) or a patient self-managing a specific disease. The system requirements will be different, including its QoS (e.g., dependability), privacy/security aspects - of what data is shared with whom (e.g., friends or practitioners), liability (e.g., what happens if battery is depleted) and further QoE aspects.

QoL Technologies Integration in the Routine Context – It is essential for any solution to be part of the actions an individual engages in his/her everyday life, particularly for chronically ill patients, who self-manage their illness daily. But this is also true for busy individuals, who do not want that QoL technologies add to their stress. Additionally, any real life deployment must embrace diversity of devices used by individuals. The key research challenge is that the context of the real world deployment may be of a major issue influencing the research, development and deployment of the QoL technologies.

3.5 Transdisciplinary Research Challenges

Trans-disciplinarity involves experts from different reputable scientific disciplines that research jointly a common complex research challenge, while synthesizing their domain-specific theories, methods, and measures in an iterative process [16], employing both hypothesis-driven and explorative approaches to solution's design and evaluation phases. Challenges of transdisciplinary effort itself relate to scientific communication of concepts, common understanding of semantics and tacit knowledge in a specific domain across a set of experts, additionally to combination of (possibility orthogonal) methodologies to advance the knowledge on the joint research challenge.

The integral part of the research on QoL

technologies is transdisciplinary effort to achieve *user-centric and holistic approach* (i.e., including physical, psychological, social and environmental view) to the individual's day-to-day QoL (c.f., Section 2) while addressing research challenges enumerated in this section from technological (e.g., infrastructure), human computer interaction (e.g., interaction design), societal (e.g., ethics, privacy and trust), psychological (e.g., behavior economics), organizational (e.g., workflow), financial (e.g., reimbursement models), and legal (e.g., standardization and policymaking) point of view in a sustainable manner; involving all the actors. Such an approach is needed while assessing the users needs and expectations for the "to be designed" QoL technologies, and for the existing ones, ideally in natural, daily life environments of user (i.e., "in the wild"), where these technologies are used on a day-to-day basis. A transdisciplinary approach is needed because of these challenges cannot be readily resolved by any one of the disciplines (e.g., technological) or one systematic methodological approach. Such research will bring new approaches to theory, design, methods, measurement, and data analysis specific to each discipline, thus deepening its depth, while enabling breath. Such a research is a long-term process rather than one short-term self-contained activity, because of the technological advances in time, along with the changing individuals' needs and expectations for these technologies.

4 CONCLUSIONS AND FUTURE WORK

This paper presents examples of QoL technologies embraced in mobile computing and communications services, and enumerates the many challenges at different conceptual levels of these services need to be addressed to be able to provide robust solutions that support the tasks of the individual and his/her QoL improvements. Mhealth is a prevalent trend in these technologies, as health is an aspect spanning across the individual's physical, psychological (including intellectual and emotional), social and environmental domains contributing to his/her QoL.

Based on our research experience and outcomes, we conclude that the field is still fragmented; different projects tackle QoL from separate domain view. We illustrate that developments in the domain of QoL technologies are technologically feasible for non-critical, limited scope cases, like e.g., physical activity tracking or mobility support. There exist critical cases, for which technologies are provided, e.g., support for schizophrenic patients. However, as it has been proven, if malfunctioning (i.e., providing low QoE/QoS) such solutions in critical cases may lead to exacerbation of the symptoms and

hospitalization of the individual. For such critical cases we cannot yet to fully assure the QoE/QoS and prevent such unfortunate implications. As Csikszentmihalyi stated, an "optimal experience is simply experience that flows according to its own requirements" [8] and we are far from that from the perspective of assuring the experience in/via QoL technologies. Additionally, we do not yet have full understanding of all the inter-relations between the use of QoL technologies and their effect on the QoL of the individual in a long term.

Overall, more trans-disciplinary efforts are needed to approach QoL holistically. The physical, psychological, social and environmental domains of QoL are intertwined and influencing each other, in a ways we are not yet having a full understanding of. The importance of specific domain may arise depending on which task at hand executed by the individual (and in which domain) is supported by the technologies and depending on how critical is this task and what are the consequences for the individual of not fulfilling it, or fulfilling it with long delays, low accuracy, or dependability. These consequences may vary from having bad mood because of an interrupted funny video to a hospitalization because of malfunctioning feedback in case of management of an illness. In general, the stress (i.e., in physical health domain) caused when relying on the QoL technologies that chronically fail to meet the individual's expectations and satisfy his/her experience, can have an effect on all other QoL domains.

Our future work area involves research on multi-methods approach for assessing the individual's QoL level in day-to-day life, and for providing significant evidence that QoL technologies improve the individual's QoL, as we have already envisioned in 2010 [17].

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