Modeling the QoE Estimation for Services of the Cyberphysical Intelligent Space

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***Abstract*— A model for estimating the quality of experience (QoE) of a cyberphysical intelligent space services is proposed. This model analyzes historical data about objective quality parameters and makes predictions whether a user is satisfied by the services provided. The models of the following services are considered: videoconferencing, corporate TV, and localization and navigation. Several common and specific quality of service parameters are detailed. The proposed model for QoE estimation is based on kmeans++ clustering algorithm. It allows to analyze the key performance indicators of a cyberphysical system and to correct system requirements at the design stage.**

***Keywords*— quality of Experience; quality of Service; QoE; QoS; cyberphysical systems; intelligent space; smart space**

I. INTRODUCTION

Organization of user interaction with cyberphysical intelligent space (CPS) is a complex process depending on variety of factors. The main indicators to assess it are so-called Quality of Experience (QoE) and Quality of Service (QoS). Generally, the first concept is considered in a broader sense [1-4]: the QoS is an objective indicator, it is determined by parameters delivered to the user in terms of measurable key performance indicators for services, applications and networks, while the subjective QoE is defined in terms of the user's emotions, his/her experience of interacting with the system and includes QoS as one of its aspects.

II. QUALITY ESTIMATION PARAMETERS FOR CPS SERVICES

Let us consider a CPS using the example of Multimodal Information and Navigation Cloud System [5], which provides the next services to users:

- Videoconferencing (VC);
- Corporate TV (CT);
- Localization and Navigation (LN).

Let us point out the main QoS parameters of CPS services and simulate QoE evaluation using machine learning algorithms (Fig. 1).

A. Common QoS parameters for CPS services

While developing the technique of estimating the multi-modal interaction between users and CPS devices, one can distinguish the QoS parameters that are specific for each service and a set of parameters applicable to all services. In particular, each user request requires fulfillment that implies allocation of software and hardware resources (audio and video channels, user session) for some period of time [6].

The main QoS parameters common for all CPS modules include time of application loading and initializing, as well as request fulfillment rates under various conditions of service load (Table 1). In [7], it is pointed out that the end-user waiting time has the greatest impact on the perception of web services in comparison to audio and video services. Thus, the request processing time is the key factor determining QoE in information services.

TABLE I. COMMON QOS PARAMETERS OF THE CPS SERVICES

Parameter	Designation	Possible values	Admissible values
Application loading time, sec	t_l^{App}	$[0; \infty)$	$[0; t_{UI}]$
Application initializing time, sec	t_i^{App}	$[0; \infty)$	$[0; t_{UI}]$
Application data actualization time, sec	t_a^{App}	$[0; \infty)$	$[0; t_{UI}]$
Rate of fulfilled requests	$f_{np}^{Success}$	$[0; 1]$	$[1–p_D; 1]$
Rate of fulfilled requests weighted by priority	$f_p^{Success}$	$[0; 1]$	$[1–p_D; 1]$
Rate of denials without conflicting requests	f_{normal}^{Denial}	$[0; 1]$	$[0; p_D]$
Rate of denials with conflicting requests	f_{stress}^{Denial}	$[0; 1]$	$[0; p_D]$
Request processing delay without conflicting requests, sec	$t_{normal}^{Request}$	$[0; \infty)$	$[0; t_{UI}]$
Request processing delay with conflicting requests, sec	$t_{stress}^{Request}$	$[0; \infty)$	$[0; t_{UI}]$

The following designations were used in the table:

- t_{UI} is the maximum user interface response time considered comfortable by the user;
- p_D is the maximum admissible probability of denial to process a user request.

The types of threshold for user interface response times are described in [8]. As a rule, users consider the interaction process as well-controlled if the response time does not exceed

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1 second. If the response time reaches 10 seconds, the user will likely be distracted by another tasks. The value of p_D is chosen according to the standard [9].

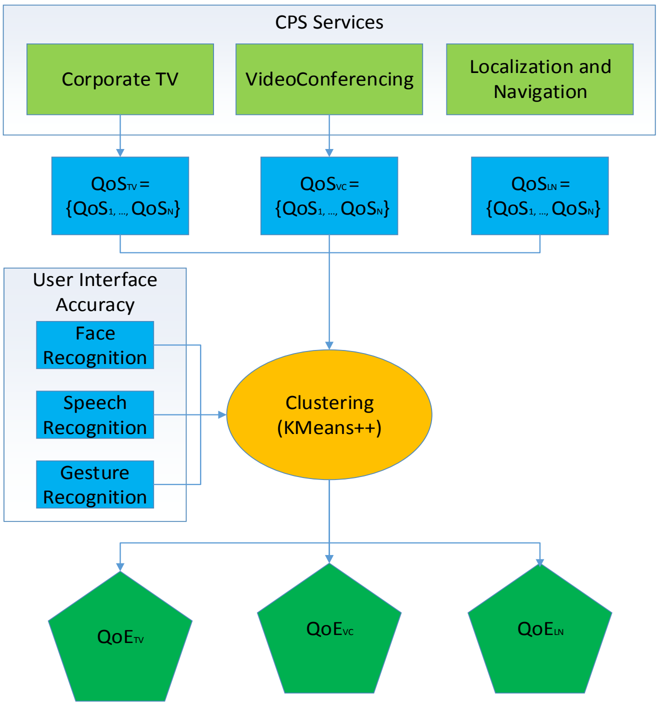

Fig. 1. Modeling QoE of CPS services

Besides the parameters listed above, the QoE of the CPS services is significantly affected by the modality of interfaces used for human-computer interaction. For this reason, the accuracy of speech and face recognition algorithms and the graphic interface usability should be taken into account. Let us consider in detail the QoS parameters specific for each service of Multimodal Information and Navigation Cloud System.

B. Videoconferencing Service

Videoconferencing is a service most sensitive to the impact of many several factors and, at the same time, it should meet the highest requirements to the perceived quality due to transmission of audio and video stream in real time between heterogeneous user devices. Since the mobile clients have a limited screen size, a relatively slow network connection, and limited battery life time, developers of videoconferencing applications should consider variability of the network environment, as well as heterogeneity of hardware and software solutions for video processing in mobile devices [10]. In addition to the common indicators mentioned above, the following QoS parameters for the VC service are distinguished [11–14]:

- *Packet Loss Rate (PLR)* defined as a ratio of packets lost with respect to packets sent;
- *Jitter*, a distortion of the periodic nature of the packet flow between the source and the destination [15].
- *Bandwidth*;
- *Security characteristics*;
- *Response time* of the peer-to-peer connection;
- *Consumption of CPU and RAM resources* of the application client and server parts.

To model the quality of the VC service, we consider the following parameters (Table 2). The data used for simulation were obtained empirically [10].

TABLE II. QOS PARAMETERS OF THE VC SERVICE

Parameter	Designation	Possible values	Admissible values
Response time of the peer-to-peer connection, ms	t_{resp}	$[0; \infty)$	$[0; t_{acc}]$
CPU consumption of the application server, %	r_{CPU}^{Server}	[0; 100]	$[0; l_{CPU}]$
RAM consumtion of the application server, Mb	r_{RAM}^{Server}	$[0; C_{RAM}]$	$[0; l_{RAM}]$
CPU consumtion of the application client, %	r_{CPU}^{Client}	[0; 100]	$[0; l_{CPU}]$
RAM consumtion of the application client, Mb	r_{RAM}^{Client}	$[0; C_{RAM}]$	$[0; l_{RAM}]$
PLR, %	f_{PLR}	[0; 100]	$[0; k_{PLR}]$

a.

The following designations were used:

- t_{acc} is the maximum response time of the peer-to-peer connection considered comfortable by the user;
- l_{CPU}, l_{RAM} are the maximum admissible loads on the CPU and RAM determined by the specifics of the server hardware and the client device capability;
- k_{PLR} is the maximum admissible PLR.

C. Corporate Television Service

The CT service communicates with users by means of stationary cameras and displays placed in various locations of the corporate territory. Moreover, users can control the service using their portable devices. The service tasks consist in broadcasting information for employees and guests (news on the institute and its activities, current research and development works, congratulations) on their requests or by schedule.

QoS parameters of this service are determined by delays, denials and losses that occur while broadcasting the media [6]. For the CT service modeling we used the parameters presented in Table 3.

TABLE III. QOS PARAMETERS OF THE CT SERVICE

Parameter	Designation	Possible values	Admissible values
Delay between the scheduled and the actual broadcasting time, sec	t_{Delay}^{CT}	$[0; \infty)$	$[0; t_{distraction}]$
Relative idle time	f_{down}^{CT}	[0; 1]	$[0; t_{distraction}]$

Parameter	Designation	Possible values	Admissible values
Broadcasting time and information amount ratio, bit/sec	$r_{perception}^{CT}$	[0; ∞)	[R_{min}; R_{max}]
Media loading time, sec	t_{load}^{CT}	[0; ∞)	[0; t_{UI}]
Rate of fails while loading the content	f_d^{CT}	[0; 1]	[0; p_D]
Rate of losses in time	f_t^{CT}	[0; 1]	[0; 1–I/I_{max}]
Rate of losses in content	f_i^{CT}	[0; 1]	[0; 1–I/I_{max}]
Distortion coefficient	k_d^{CT}	[0; ∞)	[0; 1–I/I_{max}]

The following designations were used in the table:

- $t_{distraction}$ is the period of time after which the user will be with high probability distracted by another tasks [8];
- I is the amount of information in a mediafile, bit;
- I_{max} is the threshold of the maximum admissible amount of information in a mediafile, bit;
- R_{min}, R_{max} are the estimates of the minimum and maximum rates of perceiving information by the user, bps.

D. Localization and Navigation Service

Orientation within an unknown environment can be complicated for some users. The algorithms for user indoor navigation, based on his/her actual position detected by various localization methods and destination location, include determining an optimal route, tracking the user and comparing his/her actual route with the planned one, and providing recommendations in case of difficulties. While the user follows recommendations and moves within the intelligent space, the system updates dynamically the evaluation of his/her location and generates new directions as the user reaches control points [16].

The model of LN service was developed using Unity 3D environment. This model simulates a floor of building equipped with CPS sensors for user detecting and users walking on it. The QoS parameters of the LN service depend on the next issues [17]:

- environment morphology;
- localization system structure;
- properties of particular technology used for user indoor tracking (WiFi, UWB, ZigBee, RFID, Bluetooth, etc.)

The main QoS parameters taking into account are (Table 4):

- localization accuracy determined in our case as the error of the trained random forest algorithm for user tracking;
- Position Report Frequency (PRF) determined on the stage of system hardware development.

It should be taken into consideration, that the PRF, on the one hand, affects the accuracy of user localization (the higher PRF, the more precise real time location estimate), but on the other hand, it increases load on the network (too high PRF can overload communication channel between the client device and the server). Also, it can cause fast discharging of the mobile device battery.

TABLE IV. QOS PARAMETERS OF LN SERVICE

Parameter	Designation	Possible Values	Allowing Values
Localization Accuracy	Acc_{loc}	[0; 1]	[Acc_{min}; 1]
Position Report Frequency, 1/s	PRF_{loc}	[0; PRF_{max}]	[PRF_{min}; PRF_{max}]

The following designations were used in the table:

- Accmin is the minimum admissible accuracy of the location prediction algorithm, trained on historical data;
- PRFmin, PRFmax are the minimum and maximum admissible position report frequencies.

III. QOE EVALUATION USING MACHINE LEARNING

It is necessary to evaluate mathematical representation of the relationship between key performance using mathematical model of QoS/QoE for all services of a system to evaluate the user QoE and establish its correlation with QoS parameters of CPS services [12]. The dataset with QoS parameters considered above was generated for QoE assessment simulation (Fig. 1). To mark up the data, the k-means++ algorithm (the scikit-learn library for Python) was implemented. The initial data were previously standardized: the mean was reduced to 0, the variance was reduced to 1. To establish the algorithm parameters, it is supposed that user can rate the services of CPS on a five-point scale. Consequently, the algorithm should split the unsupervised data into 5 clusters. The result of clustering after dimensionality reduction from 46 to 2 using principle component method (the scikit-learn library) for each service and for the whole CPS is presented in Fig. 2.

IV. CONCLUSION

The proposed model of perceived quality evaluation for CPS services allows one to make conclusion whether user is satisfied of provided services. It is based on historical data about objective parameters of quality of service obtained during user’s interaction with the system. Analyzing the data allows to find out what parameters affect the most on the subjective user evaluation of service. The proposed model, undoubtedly, needs to be validated based on users questioning after CPS deployment within an organization or a facility, but it can be used on the stage of development to monitor key performance indicators of CPS and to verify whether they meet the system requirements.

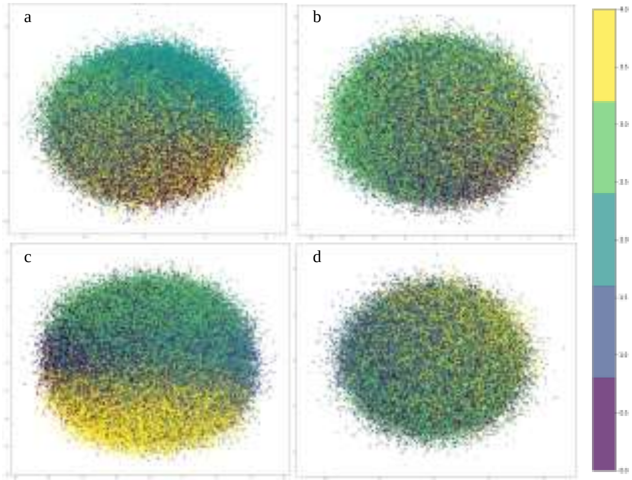

Fig. 2. Result of clustering the QoS data for CPS services performance modelling: a) videoconferencing; b) corporate TV; c) localization and navigation; d) integral services' evaluation

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