Design of Framework to Quantitatively Measure the ubiquity of an IT Solution

Anil Kumar Mishra, Yogita Gigras, Latika Singh

***Abstract:** Ubiquitous computing is one of the most disruptive and emerging technology of present times with applications in many areas like manufacturing, healthcare, real estate etc. Design of standards and framework for these applications is an ongoing research area. To aid a better design, it is worthwhile to have a framework that can be used to quantitatively measure various features of IT solutions and products like ubiquity, security etc. The primary aim of having this framework is to assist in development of a solution or product that is properly engineered. This paper provides a novel framework which includes various metrics that measures various features of an IT application or product. The application of the framework is demonstrated by measuring the various features of two different versions of a smart home application developed by a company for luxury real estate project. Initially, the first version of the application is evaluated using the proposed framework which then helped in identifying the improvement areas which were enhanced in subsequent version of the solution. These results are presented to validate the proposed concepts and model.*

***Keywords:** Framework, Ubiquitous computing, Ubiquitous application.*

I. INTRODUCTION

The landscape of ubiquitous computing is rapidly increasing. According to International Data Corporation (IDC), it is expected that worldwide spending on such IT solutions is going to touch $1.2T in 2022, attaining a CAGR of 13.6% over the 2017-2022 forecast period. With parallel growth of technologies like artificial intelligence, machine learning, 5G etc., are enabling innovation in product development in many crucial sectors like healthcare, security, energy, smart cities, environment and sustainability etc.

A ubiquitous solution consists of smart devices that are connected through a network preferably internet [1]. These smart devices are equipped with sensors, actuators and chips that gather data, perform certain operations and send/receive data over the network. The complete solution consists of various heterogeneous components like hardware, software, network protocols etc. [2]. This implies that traditional architectures, solution development methods and frameworks cannot be applied for making of such solutions. However, it is possible to extract several common characteristics as well like composition of services, embedding security, data integration etc. One of the most important feature to consider while developing such a solution is to consider the ubiquity (ubiquitous) level of the solution. During design and development stage, the aim is to have maximum ubiquity level within the constraints of available sensor & network technology and finances. Also during subsequent versions, the solution provider will focus in improving the ubiquity level of the solution to give better user experience.

The present study aims to provide a novel framework where new metrics are also proposed to measure the ubiquity of the solution. These are very important factors for success of any solution as the main purpose is to provide automated services to user without comprising the security and privacy.

The paper is organized as follows: in section 2, the proposed Methodology and the proposed metrics are provided, whereas in section 3 the details of the study of smart home solution are provided. The proposed methodology is applied to measure the ubiquity level of a smart home solution and the results are discussed in this section only. In section 4, conclusion and discussion is provided where it is discussed how this framework was used to enhance the quality of subsequent versions of the solution.

II. PROPOSED METHODOLOGY

As discussed in section 1, the present study aims to provide a framework for measuring the quality of a ubiquitous solution or product. Advances in technology has the potential to provide efficient, secure and user friendly solutions for various sectors like healthcare, transportation, manufacturing etc. Any evaluation framework that aims to measure the quality of an IT solutions should capture main features like adaptability, awareness about the environment etc. The proposed framework consists of metrics that try to capture these features. Ideally, the solution should be easy to use, learn and adopt. The instructions should be well documented and there should be a provision to take feedback from the user. These properties are essential to address in modern day applications like smart home, smart offices etc as the prime purpose of having these solutions is the user experience and remote availability. For any ubiquitous solution, the ubiquity can be measures using following metrics

2.1 Invisibility

The solution should be able to gather information from the surroundings in which it is installed and use this data dynamically to build and run models. In other words, it is the ability of the solution to collect the data from the environment without human intervention [4]. With advances in embedded systems, hardware technologies, invisible computing has seen tremendous growth. Focus of Internet of Everything is to make things smart and connected. This means that things are made smart by attaching sensors that record various parameters from the surroundings and take decisions based on the

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collected data. These things are also connected with each other using a range of communication technologies. These smart and connected things do not require human intervention to feed data, thus making the technology invisible.

From metrics point of view, invisibility is defined as ability of a solution or product being present in objects/things without being visible to the user of the application. Overall, these things enhance user experience as the objects are perceived as intelligent.

$$invisibility = \frac{number\ of\ smart\ objects\ in\ the\ given\ solution}{total\ objects\ in\ the\ given\ solution}$$

The invisibility values may vary from 0 to 1, where 0 is minimum and 1 being maximum. Here 0 would means none of the objects present in the solution is smart and will require human intervention or command. Whereas a value of 1 would mean all the objects are having intelligence.

2.2 Context Sensitivity

This refers to property of the solution that can sense physical environment and change their behavior accordingly [5]. For example, location based services in mobile devices that tell user about various types of utility services that are present in vicinity. The term is more popular with mobile systems that try to sense three main aspects namely location of user, other users around and the resources that are present nearby [5]. Several metrics have been defined in the past to measure this property based on the type of application it is being evaluated for. For example, for mobile applications it focuses on identifying whether the app is providing location services or not. In the present study, the aim is to measure context sensitivity of smart home solution. In this type of application services like location sensitivity is not applicable. Hence, the present study has defined new metrics for measuring sensitivity towards available communication technologies like Bluetooth, WI-Fi etc.

$$context\ sensitivty = \frac{number\ of\ automatic\ switch\ b/w\ communication\ technologies}{number\ of\ switches\ that\ are\ possible}$$

This metric is trying to capture if the solution has a provision to change the communication technology based on the proximity of the user to home and availability of communication technology. For example, the mobile app which is a part of the smart home solution works on both Bluetooth and Wi-Fi, can it switch automatically to Bluetooth when the user is in the house and within the range of Bluetooth and vice versa.

2.3 Experience Capture

It is expected that any IT solution or product should have a mechanism to capture user experiences, take feedback and incorporate the relevant ones in future versions [6]. With advances in technologies newer methods of capturing user experiences are evolving. The present study defines this metrics for smart home applications as follows. It is proposed to check whether for each feature offered by the application, experience is captured or not. In other words, experience capture metrics is defined as follows

$$Experience\ Capture = \frac{number\ of\ features\ for\ which\ experience\ is\ captured}{total\ number\ of\ features\ in\ the\ solution}$$

For example, if the application is offering 20 features, however, has a provision to record user feedback only for 14 features then the experience capture value will be 0.7. This is an indicator that user experience is captured in 70% of the features. In ideal situations where experience is captured for all the features of the solution, the value of this metric will be 1.

2.4 Service omnipresence

It is a characteristic of ubiquitous computing systems which allows users to move around with the feeling of carrying the services with them [7]. As indicated by the name "omnipresence" this is property of being present everywhere. To measure this, it needs to be seen whether the features of home automation are available through mobile application which can be used from anywhere across the world. Additionally, if the mobile application is available does it provide access to all the services of the solution or not.

$$Service\ omnipresence = \frac{number\ of\ services\ that\ can\ be\ accessed\ remotely}{total\ number\ of\ services}$$

In best case, all the services of the solution will be available using remote access which will make the value of this metric to be 1. In worst case, this will be zero indicating the fact that none of the service is available for remote access.

2.5 Adaptable behavior

Ubiquitous applications should be adaptable such that these react to the changes in their environment [8]. This is particularly relevant for adaptation to newer technologies. For example, if a mobile application is written for android, what is the provision to update this whenever new version of android is launched. For smart home solution, this would mean that out of many communication technologies available, which are the ones that are supported by the solution.

$$Adaptable\ Behavior = \frac{number\ of\ communication\ technologies\ supported}{total\ number\ of\ communication\ technologies\ available}$$

In smart home based application this would require additional cost as usage of these technologies would require additional hardware as well. In best solution this value will be 1, and in worst case this will 0.

2.6 Service discovery

This characteristic refers to the opportunistic services that are required for complex ubiquitous cyber-physical systems [9]. For making adaptable system, it is essential for the system to have self-discovery. For the present study, it is checked whether service discovery features are built in the solution or not.

2.7 Spontaneous interoperability

It is the ability to change partners during its operations and according to movement [10]. For a smart home application this would mean in different places of the house, similar commands should work based on the movement and location of the user. For example, if a user goes from one room to the other and gives voice command to switch on the light, it should be the light of the room where he/she is present.

$$spontaneous\ interoperability = \frac{number\ of\ controllers\ that\ support\ spontaneous\ pairing}{total\ number\ of\ controllers}$$

To measure this property, it needs to be seen how many services requires unique command and how many of these require generic ones. For example, if there are 3 tube-lights in a house in three different rooms with a provision of voice control, will these require different commands or similar one. In ideal situation, the commands should be similar, based on the proximity of the user the system should interpret the commands.

2.8 Heterogeneity of devices

This characteristic indicates the availability of application for multiple heterogeneous devices [11]. This is for application layer part of the ubiquitous computing system. Most of such solution come with mobile applications and desktop dashboards. It is essential to see if these applications are platform dependent or independent. In case these are platform dependent, are these available for all the possible platforms or not. For example, if the solution is cloud based web application, then it is platform independent. However, if it based on apps written for Android, iOS etc., the applications are platform dependent. The metric to measure this will examine the percentage of platforms for which the application is available.

$$Heterogeneity\ of\ devices = \frac{number\ of\ platforms\ for\ which\ the\ app\ is\ available}{total\ number\ of\ platforms}$$

For platform independent applications this value will be 1 which is the ideal case.

2.9 Fault tolerance

It is the ability of solution to adapt itself in situation of partial or full failure of environment [12]. This is particularly more relevant for communication technologies. For example, can it operate off-line in case availability of network for internet is not there. Similarly, in case of failure of Bluetooth can the system automatically switch to the other communication technology which is working. This can be measured by how many of such backup options are available out of all the possible combinations. Again a higher value is better,

$$Fault\ tolerance = \frac{number\ of\ backup\ options\ provided}{total\ number\ of\ combinations\ possible}$$

2.10 Functional Composition

This is the ability of ubiquitous computing system to create a new service required by the user which is based on the basic service only [13]. For smart home related application, this would mean out of all the possible services that can be made available to the user how many are provided. For example, the application basically supports controlling lights, fans, home appliances etc that are based on rely control. This metric would measure out of all the appliances, how many are covered in the given solution.

$$Functional\ Composition = \frac{number\ of\ devices\ covered\ under\ the\ solution}{total\ number\ of\ devices\ available}$$

Again, higher value of this metric is required for have a better user experience. If the solution is custom-made that it is easy to get higher values of this solution, however, if it is a standard product, it will depend upon the size and complexity of the system where it is installed.

2.11 Voice, Gesture and Language Support(VGL Support)

With advances in artificial intelligence technology and natural language processing, most of the smart home applications are equipped with voice, gesture and multi-language support. This mean that a user should be able to control the devices using voice or gesture command. Additionally, in case of voice command does it have support for different language or not. This can be measured using following metric.

$$VGL\ support = \frac{number\ of\ features\ (V\ or\ G\ or\ L)}{3}$$

The highest value of this metric will be 1 where all the three features are incorporated and the lowest will be 0 where none of these features are present.

2.12 Redundancy of sensors

It is very important to have redundancy in installation of sensors. This will ensure uninterrupted services in case of failure of sensors. Since the cost of these terminal components of the solution is not very high, it is always advisable to have multiple to ensure fault tolerance. The metric is defined as follows.

$$redundancy = \frac{total\ number\ of\ unique\ sensors}{total\ number\ of\ sensors}$$

A lower value of this metric is desired as that would indicate more redundancy. For example, if there are five unique sensors and two of each are installed in the system then the value of redundancy will be 0.5, however if one installation of each sensor is there then the value of the metric will be 1.

2.13 Privacy

This metric is used to measure the application level security of the solution. Basically to ensure that applications require user authentication or not. It is advisable to have user authentication in operating the app even if the app is not available in public domain. It is measured by checking the number of features that require user authentication.

$$privacy = \frac{number\ of\ features\ that\ require\ user\ authentication}{total\ number\ of\ features\ provided}$$

A high value is considered to be good as that would indicate that most of the features would require user authentication. The highest can be 1 where all the features are covered under user authentication and lowest can be 0 in which case none of the feature would require user authentication.

2.14 Percentage of active devices

This is to check at any given point in time how many devices of the solution are working. It is generally available at the dashboard of service provider as they will require this for maintenance and operations. This can be measured as follows.

$$\text{percentage of devices up} = \frac{\text{unique devices that are currently active and working}}{\text{total number of devices avaiable in the solution}}$$

This measure captures only unique devices. For example, there may be two micro-controllers provided in the solution to make sure that if one fails the other one becomes active. However, while calculating the given metric only one of the two will be considered as it is expected that at any given time only one should be active. A higher value of the metric is desired as this would indicate that all the services of the solution are working at the time of consideration.

2.15 Number of active users

This is a measure that tries to capture the utilization of the solution or product. This is generally measured using the logs of the applications that are provided with the solution. For smart home applications this can be measured on a weekly basis. Like how many times did a user used a particular feature in a week. This can be measured feature wise and is a good indicator of the usage of features. The metric is defined as number of times a feature is used in a week. This value is dependent on many factors like how much time is it required to be used, what is the pattern of the use of installed solution. However, a comparative analysis of this metric across all the features that are provided is essentially required to determine the under-utilized features of the solution.

This is the proposed framework where multiple metrics are devised that can measure the ubiquity of a given solution and product. With advances in technologies it is expected that the modern day solutions become more ubiquitous. Further, in the study, the application of the proposed framework is demonstrated by determining the ubiquity of a smart home solution. In the next section, the details of the given smart home application are provided. In the results section, the proposed metrics are calculated.

III. RESULT ANALYSIS

The real project was taken as a smart home solution provided by an Indian company called Ansyst Consulting. The solution provided features like controlling the lights, fans and electric appliances like water heater etc. The solution was based on both Bluetooth and Wifi. Mobile application was also provided along with solution to have better user experience. It also supported controlling devices using Alexa. Standard product included support for 2 bedrooms, drawing/dining room, kitchen and two toilets [14]. For bigger house, it required customization for adding more controllers at additional cost. The solution has one-year warranty and backend support. The authors worked with the company professionals to determine the ubiquity of this solution using the proposed framework. The results are described in next section.

As discussed in section 2 and 3, the present study measures the ubiquity of a smart home solution whose description is provided in section 3 using the proposed framework. All the fifteen metrics were calculated by the authors in consultation with designers and developers of the system. The results are provided in table 1.

S.No	Metrics	Value	Remarks	Suggestions
1	Invisibility	0.34	One of the three main category of features had sensors	It is recommended to have more sensors in future version
2	Context Sensitivity	0.25	Only 3 out of the 12 features identified had context sensitivity	Needs to focus on increasing this parameter by reducing the command based approach to automatic sensor based approach
3	Experience Capture	1	Feedback incorporated for all the features in the app	The mechanism for feedback is traditional. Newer methods can be used
4	Service Omnipresence	0.89	Out of 27 features identified for this 24 are already functional	Good performance in this domain
5	Adaptable behavior	1	Due to usage of cloud based services and app for latest version of android	Can be taken as it is in next version
6	Service discovery	0	Did not aim to incorporate public services	In the next version, will incorporate some features
7	Spontaneous interoperability	0.45	Only 12 out of 27 features identified have common interface	In subsequent versions, Can be made more user friendly by having less number of commands
8	Heterogeneity of devices	0.34	App available only for Android in the first version	It is recommended to have app for all the three mobile platforms
9	Fault tolerance	0.6	Out of 5 combinations identified, only 3 could satisfy the criteria	Should be taken care of on priority basis to have better user experience
10	Functional Composition	0.74	Out of 30 identified features 22 are already provided	More flexibility is required in offering in terms of features

				provided
11	VGL Support	0.34	Only voice commands taken. No gesture control. Only English supported	May be offered as additional feature with additional cost
12	Redundancy of sensors	0.5	Half of the sensors are duplicated	May be offered as additional feature with additional cost
13	Privacy	1	All the features require user authentication	Can be taken as it is in next version
14	Percentage of active devices	0.9	It is an average of one month of operation	Should be improved in next version
15	Number of active users	0.72	It is an average of all the features during one month of operation	Meets the expectation of the developers

After performing this analysis, the gap areas were analyzed. It was found that more sensors and automation is to be installed to improve over-all user experience. This will improve two metrics namely invisibility and context-sensitivity which capture one of the most essential characteristics of ubiquitous solutions.

IV. CONCLUSION AND FUTURE WORK

The present study is an attempt to provide a framework for measuring the ubiquity of a solution or a product. This is useful for measuring the quality of the solution that are already existing, particularly identifying areas to be taken care of in subsequent versions. It is also useful during design stage of ubiquitous solution. In this paper, the framework is described that measures the quality of a ubiquitous solution by using certain metrics. The application of the framework is shown by applying this on a smart home solution of a company. The metrics were determined in consultation with the designers and developers of the company. Subsequently, feedbacks on various features were provided which led the team to decide the priority of offering in subsequent versions of the solution. In future, the work can be extended by giving different weightages to the metrics.

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