The Proposed Method of Measuring How Mixed Reality Can Affect the Enhancement of the User Experience

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Abstract - The rapid development of technology and the acceptance of augmented reality (AR) and mixed reality (MR) opens a new chapter in human behavior. AR & MR is changing how we walk, interact with other people, and live in physical and digital worlds. The line between the two worlds is becoming increasingly blurred. With a wide range of possibilities, the potential of AR & MR to create new value for a person lies in its ability to create an enhanced personalized user experience in different aspects of human life. This paper proposes the methodology of measuring the extent of mixed reality influence on the user experience enhancement for the museum visitors. It measures the visitor's emotion type and level of emotional intensity during the artwork observation. Microsoft Kinect is used as a measurement device to determine emotion type and level of emotional intensity. Microsoft HoloLens will guide a visitor through the correct sequence of steps and ensure that all parts of artworks are visited in the correct order. The high precision of measurements obtained by Kinect and HoloLens make all measurements highly objective.

Keywords: artificial intelligence (AI), mixed reality (MR), augmented reality (AR), virtual reality (VR), digital content, enhanced user experience, museums, culture, artifacts, tourism, multimedia, enhanced personal experience.

I. Introduction

The broad availability of mobile smart devices like smartphones, tablets, wearables like smartwatches, and, in recent times, head-up displays (like smart glasses and other devices) enable humans to use them as a technological extension of themselves. Those devices are used in everyday activities like checking what is new on the social network, different shapes of entertainment (games), but also as helpers for tracking physical activities, learning, searching for information, and other aspects of our life. Mobile device use is prevalent among the young population, but today almost all age groups use mobile devices. That statement is substantiated by statistical data: nearly 60% of worldwide users use mobile devices, which corresponds to surveys related to "Digital Society" in the European Union, as stated by Eurostat regional yearbook 2021, for individuals aged 16 to 74 years (data is from the period of 3 months before the survey has been executed in 2020.).

Thanks to the availability of powerful mobile devices that can run AR/MR/VR applications and content, technologies considered Sci-Fi in the past became a reality today. This creates new expectations on user experience (UX) that do not affect just the virtual environment but also the physical world around us. Different aspects of human life are involved, and researchers are eager to learn how the user experience can be enhanced in different situations. One of the areas of researcher's interest is the museums. The authors of this paper focus on measuring the user experience of museum visitors.

Museums have been experimenting with various forms of digital experience, but mainly to introduce plain facts or static information about physical artifacts without attempting to engage visitors and motivate them to visit the museums several times [1]. It is no longer enough to hang a masterpiece painting on a wall and provide basic information on a side sticker to attract visitors back to the museums. New tourists/museum visitors expect a personalized, stimulating, and interactive user experience [2].

To further illustrate existing efforts, here are a few examples of the use of AR/MR/VR in world-famous museums:

1. Smartphone-guided museum tour in Museu Egipci Museum in Barcelona, Spain. Complements human guides and enables the creation of personalized tours, Figure 1

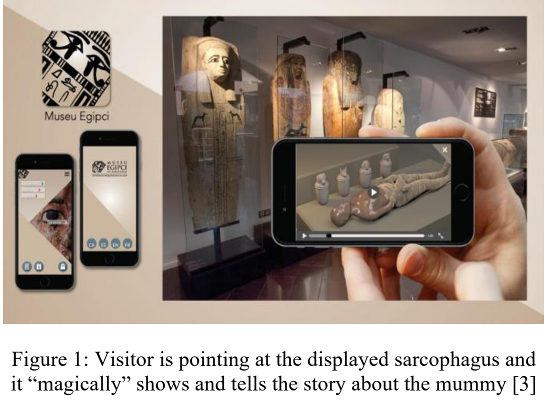

Figure 1: Visitor is pointing at the displayed sarcophagus and it "magically" shows and tells the story about the mummy [3]

2. Virtual reality (VR) project named “Mona Lisa: Beyond the Glass”, Figure 2. It has been developed for the Louvre Museum in Paris, France. Even though it is not an AR application, it allows visitors to visit a “virtual” exhibition and experience (not just see but also hear) the story of one of the most famous paintings in the world. Different historical and research sources have been combined with animation and exciting storytelling to make visitors more engaged.

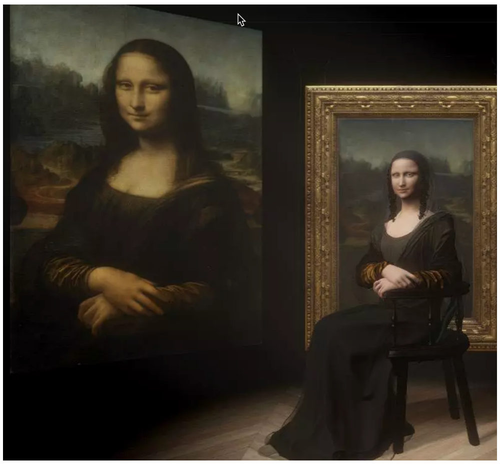

Figure 2: "Mona Lisa: Beyond the Glass" the Louvre’s first virtual reality project [4]

3. HuffPost RYOT used augmented reality technology to bring the Louvre Museum directly to the young children in Los Angeles, USA, Figure 3. Important project from the social and community point of view that promotes inclusiveness.

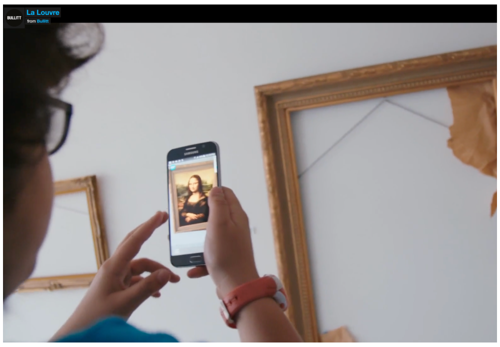

Figure 3: AR App maps digital content-Mona Lisa painting-on the empty frame on the wall [5]

4. AR application for mobile devices developed for Musée d'art et d'histoire (MEH) in Geneva, Switzerland. This application enables visitors to point mobile devices (smartphones or tablets) to the damaged statues and see 3D visualization of damaged statues as originally made, as shown in Figure 4.

Figure 4: 3D visualization of damaged statues [6]

5. Joint Chinese-Croatia R&D project included the development of hardware – a mobile device/specially designed tablet that looks like a magnifying glass and accompanying software for use in museums.

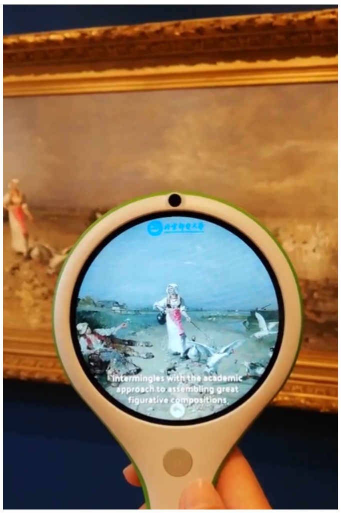

Figure 5: Specialy designed tablet pointed to the painting displays narrated multimedia content (photo taken by authors) [7]

The content was prepared by the curators of the Croatian National Museum of Modern Art. The Faculty of Graphic Arts team in Zagreb created scenarios for digital content. When a special tablet camera is pointed at a painting, as shown in Figure 5, the digital content assigned to that painting is displayed on the device screen. It can be sound, video, animation, image, text, or 3D objects mapped to the painting.

In all examples, the levels of originality and the quality of the presentation of multimedia content are critical. Content is what people see and hear, and it shapes their experiences. That is what makes the “wow” effect. Without high-quality multimedia elements and content enhanced user experience cannot be reached. More examples can be found in the paper “Artificial Intelligence (AI) Brings Enhanced Personalized User Experience” [8].

A. Hypothesis

The above examples raise the question: do they meet expectations to increase the user experience of museum visitors? Many research papers try to find an answer [14, 15]. This paper proposes a methodology that could help researchers find out the answer by confirming or disputing the following hypothesis: "**IT solutions based on MR applications, content, and devices can significantly improve the user experience by instigating emotional response in visitors**."

B. Motivation

Motivation for the paper came from the R&D project [7]: "Research and Application Demonstration on Key Technologies of AR Information Service in Museum Based on 4G/5G" as a part of Croatian-Chinese scientific and technological cooperation. Two academic institutions have implemented this project: the University of Zagreb, The Faculty of Graphic Arts, and the Beijing University of Posts and Telecommunications, in partnership with the Croatian National Museum of Modern Art and Croatian IT company CITUS. The objective of this project is defined as follows: "Through the construction of a visual explanation platform, the research team will build an interactive experience information service between the museum audience and the exhibits. Through the development and field tests, conferences, and expert exchange programs, the Croatian - Chinese cooperation research teams will develop hardware and software solutions for a 'people-centered' information transmission system architecture of dedicated terminal and digital content.".

One of the research objectives is: "Usability, UX and impact testing of the developed prototype and field research data analysis and development of user behavior analysis system.". Above mentioned example number 5 describes special hardware – custom-made MR tablet, application, and digital content developed during the project.

II. Methodology

Experience in testing and evaluating AR/MR systems is minimal as they are relatively new [9, 10]. Therefore, the authors of this paper have decided to propose a new methodology that will include various evaluation/testing techniques, including AR/MR itself.

The proposed methodology's results may help museums create an improved interactive user experience, but it can also be used in many other, completely unrelated scenarios.

A. Subjects

The minimum number of subjects should not be less than 30 for pilot measurement. For logistical reasons, all subjects are likely to be invited upfront. Since a measurement comparison must be made on the same subject, all subjects must participate in two different measurements.

B. Modeling emotions

The entire concept is based on the idea that it is possible to measure the difference in the emotions (of the same visitor) in different situations. It even goes further and measures not only the emotions but the intensity of those emotions and then calculates differences. The two different situations in the measurement process will be:

1. "Standard" museum experience; no additional digital content available
2. "Enhanced" museum experience; additional digital content available

The following image shows one frequently used 2-dimensional emotions model:

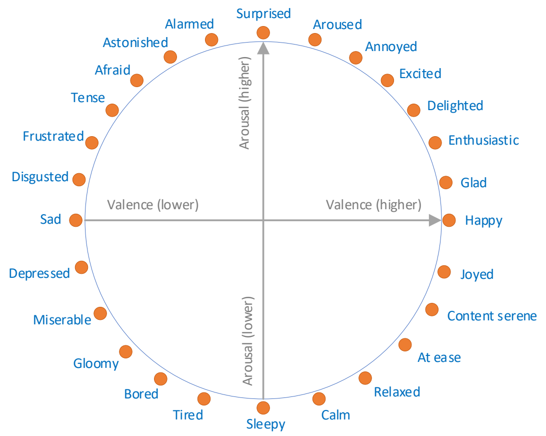

Figure 6: 2-dimensional emotions model

We can see that there are 26 predefined emotions distributed along the circle. Different models may show different emotions (both by number and by name), but that does not affect the basic idea.

We have to rely on some predefined, previously agreed framework describing emotions [11, 12, 13, 14]. There are several possibilities, and all of them are based on the same general idea: all emotions can be represented as a superposition of some basic (usually two, but there are models that use three or more) dimensions. In 2-dimensional models, the two dimensions are usually **Arousal** and **Valence**, but some other names are also used.

Similarly, if we introduce a third dimension. This is usually related to a time passage (**Past** or **Future**). The following image shows one frequently used 3-dimensional emotions model:

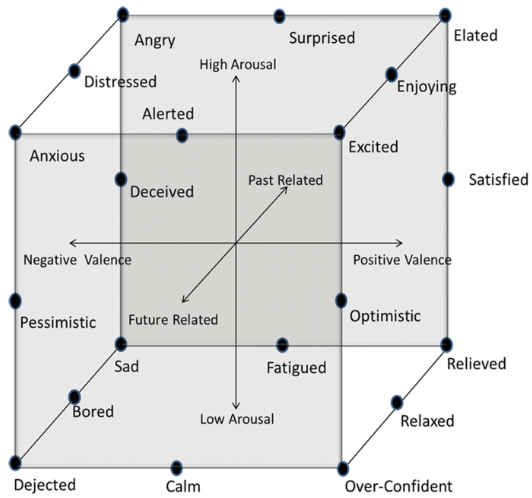

Figure 7: 3-dimensional emotions model [15]

We can see that, compared to the previous 2-dimensional model, the total number of predefined emotions is lower in this 3-dimensional model. Also, some of the emotions have different names, but the basic idea is still the same: every emotion can be represented as a combination of the influence of the basic underlying dimensions.

For this paper, we will use a 2-dimensional model, but all operations can be defined on the 3-dimensional model using the very same logic.

We will introduce some modifications to the model because we want to detect not only the emotion itself, but also measure the intensity of that emotion. The first extension will be dividing a circle into 5 levels, each level corresponding to the intensity of some specific emotion:

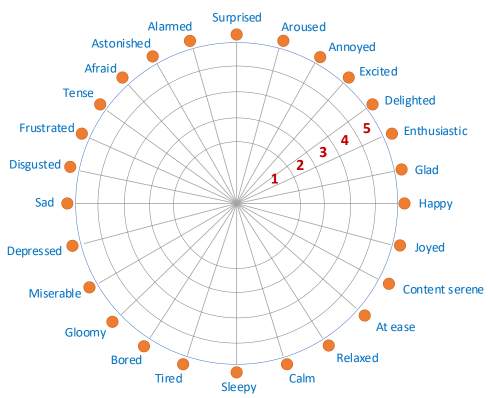

Figure 9: 2-dimensional emotions model with 5-level intensities

Five levels have been chosen for purely practical reasons. It is simple enough that virtually any software can differentiate within the five intensities of the same emotion. On the other hand, five levels give enough information for rigorous mathematical calculations. This would transform the initial circle into a circle consisting of 130 (26x5) individual member areas, representing 130 possible results of any measurement.

Clearly, we could perform a very similar process for a 3-dimensional model by partitioning the initial cube into five positive and five negative layers of individual cubes. This would transform the initial cube into a cube consisting of 1000 (10x10x10) individual member cubes, representing 1000 possible results of any measurement.

C. Measurement

For each artwork, two measurements series must be performed on each visitor (subject):

1. Viewing the artwork only using measurement devices (Kinect & HoloLens)
2. Viewing the artwork using measurement devices (Kinect & HoloLens) and a mobile device with the AR/MR application and digital content

The intensity of the expressed emotion is quantified and mapped to a scale from 1 to 5. A value of zero (0) indicates the absence of any emotion.

At this point, we must note that not all (if any!) cameras and software can return the values for all emotions in our model. Realistically, the actual number of supported emotions will typically be 3-5 times lower (6-9 emotions), and this requires the modification of the model itself (a different number of correctly placed emotions), but it still does not influence the overall methodology.

Based on the experience in previous research projects [16, 17], Kinect Measurement Protocol has been modified, and a new HoloLens Measurement Protocol is being developed.

Measuring the extent of mixed reality influence on the user experience enhancement for the museum visitors will be done by measuring:

1. The part of the artwork the visitor/subject is currently observing
2. The emotion expressed by the visitor/subject
3. The intensity of the expressed emotion

These three parameters will be used to analyze results and draw conclusions.

Microsoft Cognitive Services (a software used with Microsoft Kinect) returns these seven (neutral is not an emotion, it is rather an absence of any emotion) emotions: **anger**, **contempt**, **disgust**, **fear**, **happiness**, **sadness**, **surprise,** and **neutral**. It means that we will use the following 2-dimensional model:

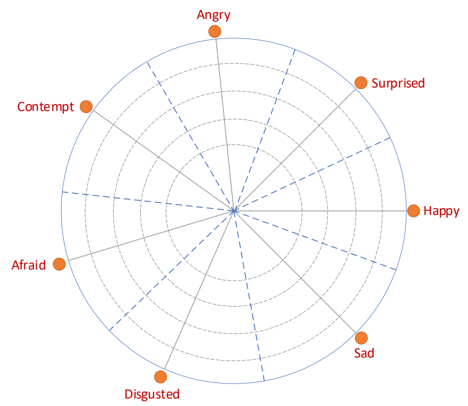

Figure 10: Modified 2-dimensional emotions model with 5-level intensities

So, each measurement will be bounded by the boundaries of the corresponding intensity (level) and left and right boundaries separating the neighboring emotions.

For example, a measurement that returns the following individual values (normalized to a maximum value of 5) for each emotion:

- Anger = 0
- Contempt = 0
- Disgust = 0
- Fear = 0
- Happiness = 4
- Sadness = 0
- Surprise = 2

The result is a set of 7 vectors positioned along the lines that represent individual dimensions. This particular set of vectors has only 2 non-zero values, and it can be interpreted in two ways. Those two possible results are represented in two different colors, as indicated in the following picture:

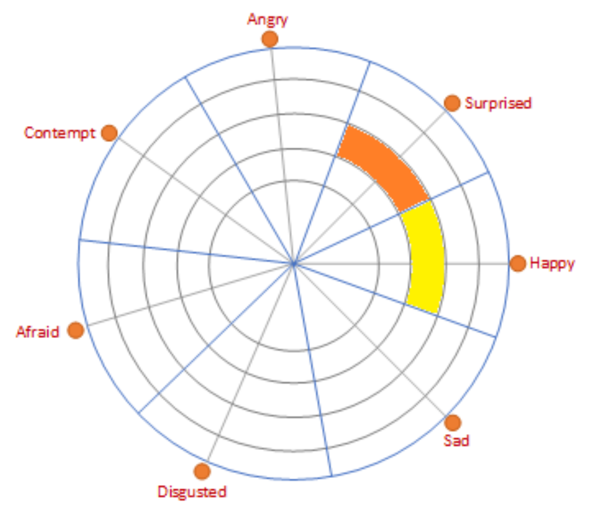

Figure 11: Possible representations of a single measurement

Generally, the final result is a vector "average" across all individual components (emotions). Basically, it is like calculating a "center of mass", only this time we are working with emotions instead of masses. The resulting value points to some area in our partitioned circle of emotions (the 2-dimensional model), and that is how we can visually represent the result of a measurement.

Sometimes, the result points to the boundary of either emotions or levels. Let us agree that we will always prefer a dominant emotion (in this case happiness, which has an intensity of 4, over surprise, with an intensity of 2). In that case, the final result of the previous measurement will be represented by a yellow area (happiness) with the intensity of 3 (arithmetical average of all measurements that returned some emotion).

If we perform two consecutive measurements on the same visitor/subject under different conditions, we will get two different results and we can ask the following question: how far are those two measured emotions? The distance can be calculated by starting from the location of the first measurement and counting the steps needed to reach the location of the second measurement. A step is only allowed between horizontal or vertical neighbors (diagonal steps are not allowed) and we would want to calculate only the shortest path (minimum number of steps).

We now have all the necessary prerequisites to define the complete process, perform the final analysis of the measured emotions and determine if the change in conditions contributed to improving the subject's/visitor's user experience.

D. The process

From the museum perspective, introducing each digital content should also be accompanied by the "emotional intention". It is the emotion (or set of emotions, represented by the corresponding set of vectors, as described earlier) that this particular digital content is supposed to instigate in each visitor/subject. So, this is the target (desired) value that will be tested by measuring the actual emotional response of the visitor.

As a result, we will get two different values: one desired (defined by the museum) and one measured. This must be repeated for each added digital content. Once we get all the measurements, we can analyze the results.

E. Quantitative analysis

Each measurement must be first compared to the desired value and the "distance" between the two locations must be calculated. This value will tell us how successful the "emotional intention" was. Small distances (lower number of steps) will indicate success, while large distances (higher number of steps) will indicate that "emotional intention" has not been reached.

The following image illustrates the calculation of one of the possible paths (green areas) and, therefore, the calculation of the number of steps needed to get from the yellow (target value or the "emotional intention") to the blue (actual measurement) area:

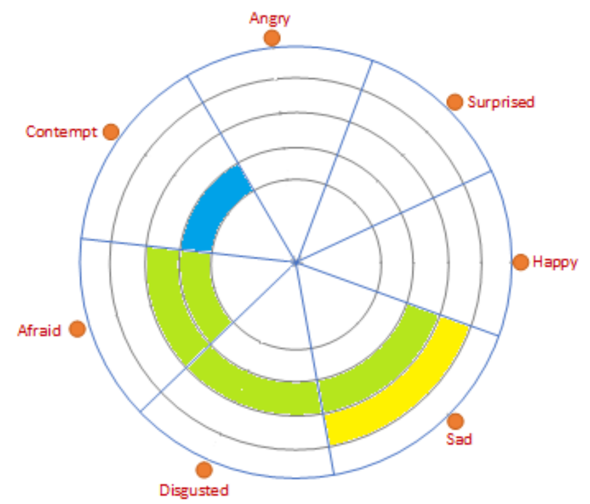

Figure 12: Representation of a "distance" in a single measurement

All individual calculations are independent, meaning that we are working with one independent variable (the "distance"). Therefore, we can apply the standard statistical analysis and calculate all values over the entire data set (all individual measurements).

By now, the process is almost complete. Expectations have been set, digital contents have been produced, and actual measurements have been taken. However, it still leaves the most important step: interpreting the results.

This may not always be unambiguous when playing with emotions, and caution is advised. However, our hypothesis can still be easily answered simply by calculating the same distances, but this time between two different series of measured results: one without the digital content, and one with digital content. Suppose we detect significant changes in emotions (irrespective of what the targeted emotions or "emotional intentions" might have been) between these two measurements. In that case, it indicates that our hypothesis has been confirmed.

III. CONCLUSIONS

The proposed methodology aims to confirm or dispute the underlying hypothesis: "IT solutions based on MR applications, content, and devices can significantly improve the user experience by instigating the emotional response in visitors.".

No measurements have been made, and the pilot project will be carried out as a part of the Croatian-Chinese R&D project [7].

The central part of the user experience is the level of the created interest in the proposed digital content. Informative, visually appealing, and otherwise attractive digital contents are much more likely to leave a positive impact on the visitor/subject.

The measurement process can be improved by introducing additional measures, for example, the amount of time spent on a specific part of the artwork.

Another possible improvement would be further partitioning of different levels of digital content for the same target. This would show what types of content create the best visitor responses.

The process can be further improved by:

1. Increasing the number of subjects
2. Using more advanced hardware and software components that can provide more reliable, more precise, and more detailed (larger number of emotions) results
3. Introducing "baseline" measurements for "standard" museum experience, taken on a sufficient number of visitors
4. Partitioning subjects into different groups according to different types of criteria

Adding the AR/MR application and digital content to the traditional museum experience creates engaging new user experiences, placing visitors in the focus instead of the museum exhibits. This opens new possibilities for further personalizations of the user experience and provides greater levels of interactivity by involving elements of gamification.

Finally, the proposed methodology (or some derivation) can be used in many other applications where measuring emotional response might be of interest. Security, psychology, and medicine are just some of the possible areas that could benefit from this.

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