Critical Technologies in the Cluster of Virtual and Augmented Reality

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***Abstract*—Technologies of creating new products in the field of virtual reality have not only been widely developed, but have already reached the payback stage - primarily in the areas of computer games and simulators for drivers and operators of complex technology, including spacecraft, airplanes, helicopters, cars, etc. As a rule, when discussing these technologies, they add so-called technologies of augmented reality to them. This is logical, but the problem is that, for example, with government funding for the development of these two technologies in a single cluster of programs, there is a danger that all actual projects will be directed to commercialization in the field of virtual reality, whereas this is not so important, since may develop in ways of self-financing. In this case, there is already a tendency to replace the enlarged concept only with its simplest component, i.e. The term "virtual reality" is used as a synonym for "virtual and augmented reality", which is completely erroneous. This article aims to distinguish between these terms. To this end, a list of critical sub-technologies has been developed, which is divided into two subsections, one of which relates only to augmented reality technologies. The article may be useful in refining the state support program designed to develop this critical end-to-end digital technology**

Keywords*—*virtual reality, augmented reality, computer games, sub-technologies, critical technologies, end-to-end technologies, digital economy

I. Introduction

As part of the implementation of the Digital Economy of Russia program, nine areas of technological development have been identified [1, 2], of which only six remained later [3]. According to the federal project "Digital Technologies" [1, 2], nine breakthrough areas included: neurotechnology and artificial intelligence, virtual and augmented reality technology, components of robotics and sensor technology, wireless communication technologies, big data, distributed registry systems (blockchain), industrial internet, new production technologies and quantum technologies. According to the Telegram-channel "Non-Digital Economy", during the Presidium meeting, it was decided to abandon the further development of three road maps: industrial Internet, big data and robotics. Including the direction of big data will be combined with the direction of artificial intelligence. Four roadmaps were adopted: blockchain, artificial intelligence, quantum technologies and technologies of virtual and augmented reality. Two more roadmaps will be finalized. These are new production technologies and wireless communications [3]. In this regard, the importance of developing roadmaps for the development programs of the remaining six end-to-end technologies (SCWT) and their sub-technologies (CT) is growing. The authors of this article took part in the development of a roadmap (DC) on this technology as involved experts. Not all the proposals of experts were taken into account, however, in our opinion, they deserve publication and discussion.

II. Statement of the Problem

The definition of virtual and augmented reality can be found on many sites, so it is hardly advisable to give them again. However, for a better understanding of the situation for the readers we will give the most basic information about the subject of research.

An augmented reality is the result of introducing any sensory data into the field of perception in order to supplement information about the environment and improve the perception of information. It is created by mixing perception of reality and created with the help of modern computer technology augmented elements of perceived reality. It is important that these augmented elements are not elements of actual reality. They can be perceived by the subject (that is, by a person equipped with the appropriate means of its formation) not necessarily in a form that is not distinguishable from reality, although it is believed that this feature is mandatory. Some experts even believe that the inability to distinguish augmented reality from reality is an important sign of the development of the corresponding technology to the required level. With this one can argue. If such illusions are created for the subject with the help of computer technologies that he cannot distinguish from reality, this is hardly always useful. It is possible that it is always harmful. In any case, there are

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many reasons for not doing this, or not always. If the subject is on the road, then the perception of the real features of the road (irregularities - holes, obstacles, puddles, etc.) is highly desirable for safe movement. Of course, if the program recreates, instead of one real obstacle, something else that is perceived differently, but overcoming it should be the same, then this may not be so detrimental to safe passage. In particular, if the perception will not match the perception of a no less dangerous obstacle than it is in reality. For example, if a subject perceives a shallow puddle as deep and this entails unwillingness to go through it, and the decision to seek a workaround is not so dangerous, but if, on the contrary, the perception of a deep obstacle is perceived as shallow, the subject can decide to overcome it that way. which should not be overcome. This is also the case with the evaluation of the strength or height of the barrier, the reliability of the bridge, etc.

If the subject always distinguishes the virtual component from the real one, this problem does not arise in principle. Therefore, at present there are many arguments for leaving objectively perceived differences of reality from virtual cues in augmented reality technology. This is not at all the same as in purely virtual reality technologies - in them the situation is the opposite: the fewer the differences between the perception of virtual reality and reality, the better, in this case the game or simulator is more effective and effective. Therefore, it is not necessary to formulate technical tasks for these two technologies, based only on those characteristics according to which they are related. On the contrary, one should seriously take into account those properties by which these technologies should differ fundamentally in their final results.

On this basis, the authors considered it necessary to compile a detailed list of critical sub-technologies based on an in-depth analysis of sources in this area.

III. LIST OF CRITICAL SUB-TECHNOLOGIES

According to Ronald Azuma's definition, a combined reality should have the following features: 1) combines the virtual and the real; 2) interacts in real time; 3) works in 3D [4].

Currently, there are several approaches to the implementation of augmented reality.

The first approach is the image of virtual reality on a computer for viewers in front of the screen. Viewers do not feel themselves in a different reality, they only see their own image, combined with virtual objects. Those. they, for example, cannot feel themselves near the dinosaur or on the surface of the moon, but see themselves on the screen next to the dinosaur or on the surface of the moon. This approach is widely used at exhibitions, however, in our opinion, it is not, strictly speaking, augmented reality, although it formally responds to these three signs. Nevertheless, it is more correct to consider this approach only as one of the components of sub-technologies, since the means for combining images in this way can serve as a useful tool for augmented reality, but they are not identical to it.

The second approach is the use of virtual reality glasses: a) for a static observer (fixed); b) for a moving observer. In case "b", the subject can move in space and see objects of augmented reality as if they are in the place where they should be, according to the task. For example, it can bypass a virtual object from all sides and view it as if it were walking around a real object. The image adjusts to the movement of the observer and is projected directly to the observer in the form of two different images, connecting them into a three-dimensional picture occurs in the human brain as when perceiving a real image. In this case, the person either does not see the actual reality at all, or it should be transferred also, as he would have seen it without glasses, only by adding virtual objects to it. In this case, the observers feel themselves in a different world that is virtually formed, they can feel close to the dinosaur or on the surface of the moon (and so on), but there are always glasses on their head, so all they see is is the result of virtual imaging. If they want to look at their hands, they can only see them if the glasses are equipped with a camera, and the program allows them to combine this reality (hands) with virtual reality. Also, these glasses can be partially transparent, which allows you to combine the actual images with the virtual ones without the formation of the actual images according to the "Camera + Screen" scheme. The objects are visible directly through the translucent screens.

The third approach is to project a picture onto several screens or onto a wide panoramic screen, changing the picture in accordance with the movement of the observer's head. This will be used in simulators or in virtual museums. In this case, sensors are located on the observer's head, which make it possible to record the position of the observer's face, for example, reflecting or fluorescent marks. The program determines the position of the head, calculates the position of the eyes, on this basis forms a picture of reality that the observer should see, and it is this picture that is displayed on the panoramic screen. In this case, the movements of the observer's head cause the entire picture to be changed, i.e. the screen deceives the senses of the observer, creating the illusion of perception of three-dimensional reality. Such screens can be installed both on the floor and on the ceiling (cube), the observer forms the full effect of being in a different space, formed completely virtually. This effect can be enhanced by sound effects, vibration, wind, etc. In this case, the observer sees his own body and objects that he holds in his hands, but as his own environment, he sees not what is in reality (a cube of screens inside which he is located), but what the virtual reality formation program offers him (images that he should see in accordance with the program). In such a situation, a person cannot go far; he must remain approximately in the same place of space. Such tools are effective for creating simulators for training in the management of complex technical means - airplanes, helicopters, automobiles, motorcycles, spacecraft, complex manipulators, exoskeletons, etc. There are messages about the cube for two observers, in this case, the separate formation of pictures on the screens can be carried out using the stroboscopic effect, for example, the glasses of each of the observers become transparent at different points in time, the image on the screen changes simultaneously; However, this idea seems to be unnecessarily complicated, since if observers have glasses, it is not clear why the screen is needed, but if there are no glasses, this idea cannot be realized in this way.

The fourth approach is the creation of a hologram. For example, there may be a cylindrical screen on which holograms are projected. An observer watching through the screen (the screen itself does not perceive the observer), it seems that behind the screen there is some object that he sees in the three-dimensional image; if the image changes in time, the observer will see a three-dimensional film. You can get the impression of combining this image with reality, for example, if the observer enters his hands or some kind of tool into the virtual location of the object. The observer may not notice the actual screen or perceive it as a normal protective glass, but the screen is important because it is the image that is projected onto it. There are numerous fake videos about how multidimensional opaque holograms are supposedly created in clear air. These videos form a false idea of the level of technology achieved in the world, which affects the improper mapping and lists of critical sub-technologies, can lead to an incorrect distribution of funding and deepen the technology lag in this direction.

The fifth approach is the formation of a virtual object by projecting an image onto suspended particles in the air. This could be fog, steam, smoke, a fine stream of particles, etc. At the same time, it is required that without illumination this external environment was completely transparent, and when illuminated it became sufficiently bright. If a color image is required, then the requirements for this medium are particularly high. Since the beam has the shape of a line in space, so that the illuminating rays themselves are not visible, and only the point that should be highlighted can be seen in two ways: a) focusing the beam at the desired point; b) the combination of several rays at the desired point. A particularly strong effect can be obtained by using a non-linearly fluorescent medium. For example, if a medium does not glow when it is illuminated with infrared or ultraviolet light below a certain power level, but begins to glow when this level is exceeded, then two different light beams, passing separately through this medium, will not create a glowing point, but in the case of their alignment the critical value of the electric field will be reached at the alignment point and this will create a bright luminescence. Further along the rays, where they will not be combined again, the medium will also not glow. This allows you to draw a luminous point in an arbitrary place in space where there is such an environment and where two (or more) of laser radiation (or radiation of a different nature) can be combined. Next, create a luminous image point by point - this may seem like a simple task, like creating a two-dimensional image in a raster way. In practice, it is extremely difficult even for such a relatively simple task, like imitation of a starry sky in a planetarium with elements of augmented reality, although in this task it would be enough just to highlight certain points in space.

The sixth approach is to modify the fifth approach. It may consist in obtaining the same effect with very high power of the lasers on natural dust particles present in almost any atmosphere. This method represents a fairly high danger to the observer's view, since in the absence of luminescent medium or scattering particles, it is possible to glow individual points of space on the naturally occurring scattering microparticles in the medium only with very high radiation power. In addition, this method is characterized by extremely high energy costs.

The seventh approach is projecting onto actual objects of reality. In this case, the image should be adjusted in accordance with the changing properties of the improvised screen. An example of such technologies is the projection on the building of a film, while the building itself has various non-uniform colors. In this method, it is also possible to distinguish two approaches, the first of which is to pre-scan such a building (collectively - the screen) and memorize its color features with the subsequent introduction of preliminary distortions into the projected image in order to compensate for these features. Another way (more so far theoretical) is that the features of the color and reflective abilities of the improvised screen are not known in advance, but are perceived after the fact and the projected image is corrected during its formation in real time. Such an approach requires an extremely large computational resource and hardware for perceiving the actual image in a form that is adequate to the perception of the observer (or observers) for whom this image is intended.

Unlike virtual reality (VR), AR does not create whole artificial environments to replace really virtual reality. AR appears in line of sight of the existing environment and adds to it sounds, video, graphics.

Today there are 4 types of augmented reality: AR without marker, AR based on marker, AR based on projections, AR based on superposition [4].

AR based markers. Some also call it image recognition, since a special visual object and camera are required to scan it. It can be anything from a printed QR code to special characters. In some cases, the AR device also calculates the position and orientation of the marker for positioning the content. Thus, the marker starts digital animation for viewing by users, and therefore the images in the magazine can be turned into 3D models.

Markerless AR. Augmented reality based on positioning or based on a position that uses GPS, compass, gyroscope and accelerometer to provide data based on user's location. This data then determines which AR content you will find or receive in a specific area. With smartphones, this type of AR usually produces maps and routes, information about nearby businesses. Applications include events and information, business advertising pop-ups, navigation support.

AR based projections. Designing synthetic light on physical surfaces, and in some cases allows you to interact with it. These are holograms that we all saw in science fiction films, such as Star Wars. It detects the user interaction with the projection of its changes.

AR based superposition. Replaces the original form complemented, in whole or in part. Object recognition plays a key role; without this, the concept itself is simply impossible. We all have seen an example of superimposed augmented reality in the IKEA Catalog app, which allows users to place virtual items from their furniture catalog in their rooms.

Devices suitable for augmented reality are divided into the following categories:

• Mobile devices (smartphones and tablets) - the most accessible and most suitable for AR mobile applications, from pure games and entertainment to business analytics, sports and social networks.

• Special AR devices, designed primarily and exclusively for augmented reality. One example is HAD displays (HUD), which send data to a transparent display directly in the user's field of view. Initially, such devices were introduced for the training of pilots of military fighters, now such devices are used in aviation, automotive, manufacturing, sports, etc.

• AR glasses (or smart glasses) - Google Glasses, Meta 2 Glasses, Laster See-Thru, Laforge AR glasses, etc. These devices are capable of displaying notifications from a smartphone, helping assembly line workers, accessing content without hands and T.D. Devices suitable for augmented reality are divided into the following categories:

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• AR contact lenses (or smart lenses) that extend reality a step ahead. Manufacturers such as Samsung and Sony have announced the development of AR lenses. Accordingly, Samsung is working on lenses as an accessory for smartphones, while Sony is developing lenses as separate AR devices (with features such as taking photos or storing data).

• Virtual retinal displays (VRD), creating images, projecting laser light into the human eye. Such systems, designed for bright images with high contrast and high resolution, have not yet been created for practical use.

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IV. Possible goals for AR use

1. Disclosure of additional information about the object. The technology involves the recognition of texts, labels, ready-made images or images of reality with the prompt provision of hidden (additional) important information about these objects, which speeds up decision making and increases their motivation (mega-task - means of ensuring operational and strategic decision-making).

How it works: currently there are product label recognition programs that can be used to find out more information about a product than it has on its label. But the label can be faked, so this technology should provide for the protection of tags of this type from counterfeiting. For example, if an unscrupulous manufacturer forged an alcohol product, it could also fake a label, i.e. Copy the quality label. In this case, the label recognition system will collide with an exact copy of the original label and recognize the product as a quality one. To avoid this situation, the labels must be such that they cannot be forged. For example, they should contain some features formed by means that go beyond the capabilities of typical copiers. Not every product has such capabilities. However, at present, means of recognizing the chemical structure of the material, for example, based on the unique emission spectrum of various atoms and molecules, are already being produced (although not too widely). In this case, such a device can distinguish real gold from counterfeit by optical spectroscopic means, determine the grade of steel, etc. Probably, using such methods, it is possible to distinguish real quality products from poor quality ones (for example, real expensive wine from fake wine), however, such devices are likely to be quite expensive in the near future and will not be widely used. When products are quite expensive, the use of counterfeit products causes significant damage, such technologies have their own prospects. In a simpler version, a relatively simple video camera may serve as a means of perception, possibly complicated by one or several means of illumination (for example, LEDs in the IR and UV ranges), which provides additional opportunities for object recognition. In particular, two indistinguishable labels printed on different color printers (not identical in nature) may be completely identical in the visible range, but with the use of IR and UV illumination they may look completely different. For example, such a technology makes it possible to ideally quickly and reliably distinguish counterfeit bills from the original ones, and also to reveal invisible inscriptions or traces of liquids that are invisible in ordinary light (secret writing) on the surface of the paper. Also, using similar methods, for example, one can distinguish the original of a picture from its copy, etc.

2. Operational measurement and recognition - determination of distances to a target, specification of directions, memorization of objects that quickly disappear from sight, etc. Human perception is not capable of reading and remembering a large amount of information in one glance. Even in order to read and remember the number of the car, it takes time, while a video camera only needs one frame to record all the information that can then be shown in the combined reality mode. It is possible to consider a fast-flowing event in slow-motion mode (after accelerated shooting), to consider the details of this event in detail. This is especially important in scientific research, but it may also be necessary in operational activities, for example, a quickly flashed face of a criminal can be recorded, processed, recognized. You can virtually remove makeup, glued mustache, beard, thick eyebrows, glasses, etc., or vice versa, virtually add makeup elements that were on the criminal to the person who has now become the object of close attention. This allows not to lose the criminal, who promptly changed the appearance by applying or removing make-up, changing noticeable details of clothing, if there is information that he is still in the observation zone, because he did not have time to hide. Also, these technologies can make it possible to identify a short-term new object in a relatively static picture, for example, when examining a “green light” in which a sniper is hidden, image processing can emphasize those image fragments that can be suspicious in order to draw attention to them as potential sniper location.

3. "X-ray vision". The technologies under which the beholder could see through the object he is looking at are definitely fantastic. However, with stationary placement of X-ray installations, these technologies can be reproduced in such a way as if the beholder could really consider the subject of interest through him. First of all, it can be extremely important when performing complex surgical operations. The patient can be shined in such a way that allows you to restore the three-dimensional image of his insides (even with the surgeon's instrument). Currently, radiation doses can be

reduced to such an extent that the level of radiation during the operation does not pose a danger to the patient, and radiation will not fall into the hands of the surgeon. At the same time on the glasses of virtual reality or on the appropriate visor or screen, the surgeon can observe the patient as if his body were translucent, and all his organs could be seen freely in the state in which they are, distinguishing healthy tissue from tumors and etc. In this case, special states of tissue can be additionally recognized and highlighted (tumor, lymph, blood, bones, etc. - all this may have additional color markers).

4. Guide (in a difficult situation, conditionally "in the labyrinth"). When performing complex operations in a complex reality - in a mine, inside a complex engineering structure, in a cave, during rescue operations in smoke filled rooms, etc. a helmet with a virtual reality screen can prompt the direction of further movement, identify the desired objects or subjects, thereby ensuring more successful actions.

5. "Night vision" - does not need comments.

6. “In touch” - in conditions when the hearing cannot be activated for one reason or another (silence mode or, on the contrary, an extreme noise level), negotiations cannot take place even with the use of headphones, since the speaker does not have the opportunity to use the microphone. In this case, the connection can be made with gestures, both sides should have a vision of each other, which is provided by an additional screen (projection on glasses or visor).

This list does not exhaust the full range of possible applications of WDR.

In addition, there are a large number of applications for entertainment and advertising purposes, which is not advisable to be covered in this section, since these areas are widely covered in the press and are already being actively exploited.

V. Virtual and Augmented Reality Technologies

Technologies for taking data from reality, including

- means of picking up optical information (in the video range, IR, UV, X-ray range): video recorders, video cameras, cameras, scanning devices together with recording devices, x-ray machines, installations of other types of electromagnetic radiation (except radio frequency range) and receivers of this radiation, as well as measuring instruments using effects of coherent radiation and the interaction of light with matter (luminescence, forced and spontaneous, etc.);

- means of electrical, acoustic or optical location, as well as measuring instruments using the Doppler effect [5–11];

- means of electromagnetic and electrical measurements;

- means of non-electrical measurements, including means of passive acoustic measurements;

- means of obtaining data fields (flaw detection, measurements of the distribution of deformations, strengths, velocity fields, etc.) and others.

Communication technologies, including

- wireless communication lines,

- optical communication lines,

- cable types of communication,

- promising and innovative types of communication and others.

Signal flow processing technologies including

- photo and video image processing technologies;

- 3D image processing technologies

- technologies for processing video files, including in real time;

- modulated signal processing technologies to extract information about modulation parameters;

- technology recognition of all types of tags and codes;

- image recognition technology, including moving images, recognition of faces, numbers, car brands, various things and their signs;

- technologies for recognizing sounds and groups of sounds, including technologies for analyzing voice signs, recognizing words and phrases, technologies for recognizing different streams of phrases with various voice features, etc .;

- technology recognition factors formed by other means of BP or WDR, including media transfer, etc.;

- technologies for processing signals streams [12–14] and others.

Virtual reality presentation technologies for human perception, including:

- image processing technologies and their combination

- technologies for presenting images on all types of screens or display devices (including HP glasses of all types);

- technologies of representation of images on objects of reality, not intended for these purposes

- technologies for the representation of images without the use of objects (including images on pairs, on aerosols, on natural scattering objects, and others).

Advanced reality technologies, including

- night vision technology;

- thermal imaging technology;

- X-ray technology;

- innovative technologies in this field and others.

Technologies of combining virtual reality with real sensations, including

- technology of combining images (including technologies of local or global compensation or suppression of actual images);

- technologies for combining acoustic information (including technologies for suppressing acoustic noise);

- technologies for the formation of tactile sensations (including technologies for suppressing or masking tactile sensations);

- technologies of heat exposure, exposure to moisture, wind, etc.;

- technology impact on human sensations in addition to the use of direct effects on the senses;

- technologies for the formation of aromatic effects (including odor suppression technology);

- technologies of forming or relieving pain (including localized by the sense organs or locally in the body);

- technologies of influence on small and medium-sized communities (groups) for the formation or suppression of massively formed and amplifying emotions (including the technologies of formation and suppression of panic);

- technology impact on taste sensations (including technology to suppress taste sensations);

- technologies of influencing the vestibular apparatus and the feeling of heaviness (including technologies of deceiving this feeling);

- technologies of weak electrical effects with the formation of the calculated effects of perception;

- NLP technology;

- technology of mind control with the help of long-term target programming (including media);

- technology impact on human immunity, his sense of strength, health, etc.;

- technologies with the use of chemical exposure agents and technologies that detect the results of chemical exposure agents, alcohol or drug intoxication, etc., as well as technologies that reduce the effects of such exposures;

- technologies for determining hormonal factors and technology of hormonal effects.

Technologies for compressed presentation of knowledge and information, including technologies for accelerated perception and memorization of this information;

Technologies of influence on the human sense of time (acceleration, deceleration);

Impact technologies during sleep or in any other non-standard state of the body;

Technology enhance the capabilities of the human body, including:

- technologies for the use of exoskeletons with power drives, controlled by the muscular strength of the operator;

- technology of electric amplifiers for power tools

- traditional and non-traditional technologies to improve the possibilities of sight, hearing, smell, touch, taste, etc.

- innovative technologies in this field and others.

Technologies based on the synergistic effect of the joint use of several technologies from the list above.

Conclusion

Based on the analysis of the main problems the paper has given the list of sub-technologies.

References

[1] URL: http://digitalrosatom.ru/proektnyj-ofis-cifrovaya-ekonomika-rf-gk-rosatom-podgotovil-pilotnuyu-versiyu-doklada-atlas-skvoznyx-texnologij-cifrovoj-ekonomiki-rossii/ Date: 06.05.2019.

[2] URL: http://digitalrosatom.ru/wp-content/uploads/2019/01/%D0%90%D1%82%D0%BB%D0%B0%D1%81-%D1%81%D0%BA%D0%B2%D0%BE%D0%B7%D0%BD%D1%8B%D0%B5-%D1%82%D0%B5%D1%85%D0%BD%D0%BE%D0%BB%D0%BE%D0%B3%D0%B8%D0%B8-%D1%86%D0%B8%D1%84%D1%80%D0%BE%D0%B2%D0%BE%D0%B9-%D1%8D%D0%BA%D0%BE%D0%BD%D0%BE%D0%BC%D0%B8%D0%BA%D0%B8-%D0%A0%D0%BE%D1%81%D1%81%D0%B8%D0%B8.pdf Date: 06.05.2019.

[3] URL: http://l.facebook.com/l.php?u=http%3A%2F%2Fwww.cnews.ru%2Fnews%2Ftop%2F2019-05-27_v_rossii_otkazalis_ot_proryvnogo_razvitiya_bolshih&h=AT1T23IjO1_ifxViJH9_1EEguuASo9ybbFkvEJQyw9DPBldBtm7kg8RmZKZb3i7pU1KsTeraVtUzdZnutwvlEtUqFfnM5a1XD2tlZ2lhdgXphSdiwF4VsjxkxZaz4qdeMtcQklt4gAhttp://l.facebook.com/l.php?u=http%3A%2F%2Fwww.cnews.ru%2Fnews%2Ftop%2F2019-05-27_v_rossii_otkazalis_ot_proryvnogo_razvitiya_bolshih&h=AT1T23IjO1_ifxViJH9_1EEguuASo9ybbFkvEJQyw9DPBldBtm7kg8RmZKZb3i7pU1KsTeraVtUzdZnutwvlEtUqFfnM5a1XD2tlZ2lhdgXphSdiwF4VsjxkxZaz4qdeMtcQklt4gA Date: 06.05.2019.

[4] https://thinkmobiles.com/blog/what-is-augmented-reality/ Date: 06.05.2019.

[5] The design of the control system for object with delay and interval-given parameters. Zhmud, V., Zavorin, A. 2015. International Siberian Conference on Control and Communications, SIBCON 2015 – Proceedings. 7147060.

[6] Method of sensitivity rise of laser vibrometers. Goncharenko, A.M., Vasil'ev, V.A., Zhmud', V.A. 2003. Avtometriya. 39(2), p. 43-47.

[7] Absolute frequency measurements in precision laser spectroscopy of Muonium. Bagayev, S.N., Belkin, A.M., Dychkov, A.S., (...),Zakharyash, V.F., Zhmud, V.A. 1999. Proceedings of SPIE - The International Society for Optical Engineering. 3736, p. 310-318.

[8] Frequency reference in the 732-nm region for precision laser spectroscopy of muonium. Bagaev, S.N., Belkin, A.M., Dychkov, A.S., (...),Farnosov, S.A., Fateev, N.V. 2000. Quantum Electronics. 30(7), pp. 641-646.

[9] A phase-locked loop system for the difference frequency of two lasers. Barmasov, S.V., Zhmud', V.A. 2000. Instruments and Experimental Techniques. 43(3), p. 381-383.

[10] Development of rotating pendulum stabilization algorithm and research of system properties with the controller. Sablina, G.V., Stazhilov, I.V., Zhmud, V.A. 2016. 13th International Scientific-Technical Conference on Actual Problems of Electronic Instrument Engineering, APEIE 2016 – Proceedings. 3,7807046, p. 165-170.

[11] Modern key techologies in automatics: Structures and numerical optimization of regulators. Zhmud, V., Yadrishnikov, O., Poloshchuk, A.,Zavorin, A. 2012. Proceedings - 2012 7th International Forum on Strategic Technology, IFOST 2012. 6357804.

[12] Modern problems of high-precision measurements of the phase differences. Zhmud, V.A., Goncharenko, A.M. 2016. 13th International Scientific-Technical Conference on Actual Problems of Electronic Instrument Engineering, APEIE 2016 – Proceedings. 1,7802284, pp. 314-318.

[13] Real time digital super-high accuracy vibrations measurements: Methods, devices and mathematical modeling for the metrology. Zhmud, V., Liapidevskiy, A. 2010. Proceedings of the IASTED International Conference on Modelling, Identification and Control. pp. 343-347.

[14] An electronic system for stabilizing the frequency of the He-Ne laser to the methane absorption lines. Zhmud, V.A., Barmasov, S.V., Gitel'son, V.D. 1999. Instruments and Experimental Techniques. 42(4), pp. 551-557.