

# APPLICATION OF AUGMENTED REALITY TOOLS TO THE DESIGN PREPARATION OF PRODUCTION

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The paper describes the application of augmented reality tools to create an auxiliary interactive tool in the field of design. To mediate it, an application with AR operation based on marker tracking has been designed. The created application works with the mobile devices platform. Two types of markers have been used in the application. To display basic information, buttons with functions are added to the scene, such as part information, rotation and change of position in the X, Y, Z direction. The application runs on a mobile phone, with a built-in camera. The marker is displayed in the drawing's lower left corner. The model is positioned so that it appears above the view of the part in the drawing. The task of the application is to support intelligent tools applicable in the design stage of production preparation, in the creation of drawing documentation.

## KEYWORDS

Augmented reality, Unity, Vuforia.

## 1 INTRODUCTION

The application of augmented reality techniques and technologies is one of the modern tools that drive economic development not only in the field of mechanical engineering. The requirements for a radical reduction in time necessary for innovation and for rationalizing the process of development lead to a rapid deployment of new methods and techniques (many have found significant application in the mechanical engineering industry) and the emergence of new technologies and approaches. Studies of new mechanical engineering projects show that the current times require the use of new approaches in all stages of production preparation and implementation [Fedorko 2016]. Augmented and virtual reality is currently evolving at a rapid pace. Progress and results are reflected directly in products designed to use augmented or virtual reality, and these products can be seen in exhibitions and presentations of various global companies operating in the field of CAD and CAM systems on the market [Monkova 2014, Michalik 2012]. The rapid development in augmented and virtual reality is the result of ever-increasing customer requirements, such as high resolution, high pixel density, high computing power growth, and low power consumption. The fundamental difference between augmented and virtual reality is that augmented reality (AR) superimposes a virtual environment on the real one and uses a camera to display things in real time, while virtual reality (VR) draws a person directly into the modeled environment. AR technology came from the simple idea of activating multiple senses, thus making it possible to achieve a much more intense experience [Novakova-Marcincinova 2017, Panda 2017]. At present, this idea is not only focused on achieving an emotional experience, but also on practical use in cooperation with a real

environment. Thanks to the technological progress that AR has undergone, it is becoming more and more accessible not only to large companies, but also to individuals. The potential of virtual or augmented reality is extensive and widely applicable also outside various mechanical engineering sectors, where it provides an opportunity to discover new technical possibilities.

## 2 AR IMAGING TECHNOLOGIES

Appropriate display technology is required to combine the real and virtual images so that they are both seen simultaneously. Different types of imaging techniques are available in AR systems, from stereoscopic displays to virtual image projection [Billinghurst 2015].

Combining real and virtual scenes for AR visualization requires a number of procedures, such as camera recording and calibration. Camera calibration is a procedure that synchronizes the parameters of a virtual and a real camera so that the computer-rendered image is properly aligned with the real-world view. Internal and external camera parameters are available. Internal parameters determine where the 3D image scene is reflected in the 2D image. External parameters define the position of the camera in the known coordinate system (Fig.1) [Billinghurst 2015].

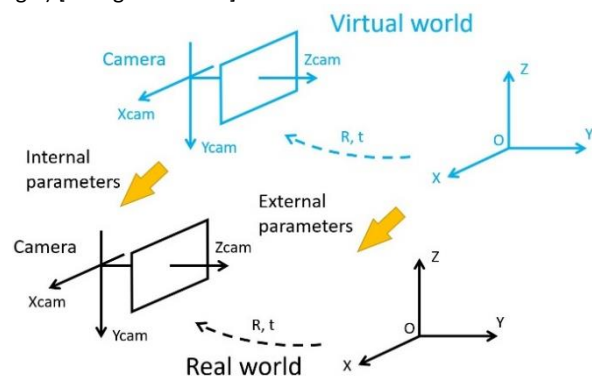


Figure 1. Internal and external camera parameters [Billinghurst 2015]

The internal parameters of a physical camera can be calculated using a process that involves capturing a set of images from a calibration pattern with known geometric properties and calculating parameters based on a match between the 3D structure of these geometric features and projecting it onto a 2D image. This is usually done offline, before starting the AR system. If a physical camera is not used to capture the real world, then the internal parameters are determined by the relationship between the user's eye and the image plane of the rendering [Billinghurst 2015].

External parameters are determined by monitoring the position of the physical camera. In a static physical scene, it is sufficient to monitor only the position of the camera, which is aligned with the actual coordinate system, while in a dynamic scene, the positions of each object should be monitored so that the change in the real world is recorded in the virtual scene [Billinghurst 2015, Kovac 2018].

Tracking technologies determine the position and orientation of target objects compared to the coordinate system. In order for the virtual scene to properly align with the real world environment, the coordination frame used to render the virtual scene should match the coordinates of the physical environment. If the virtual camera is calibrated and the virtual space is properly matched to the physical space, the rendering of the virtual scene corresponds to the user's view of the real space. The final display of a scene that contains two images (the virtual and the real one) can be obtained digitally or physically, depending on the configuration used [Billinghurst 2015].

AR displays can be categorized into four types of configurations according to how they combine a virtual image display with a realistic view, namely [Billinghurst 2015]:

- video-based imaging,
- optical see-through,
- projection of a virtual scene onto a physical surface,
- eye multiplexed.

### 3 HARDWARE AND SOFTWARE TOOLS IN AR

Developing successful AR applications is a challenging task. Despite the advances in AR technology in recent years, most of the AR systems developed so far are implemented in the laboratory or non-production conditions. Extensive research has been conducted around the world to address some important issues in AR technology. Real-time monitoring and calculation are very important, because synchronization between the real and virtual world must be achieved in the shortest time possible [Blasko 2019].

AR applications are being intensively developed for both hardware and software. Special equipment such as head displays, and accurate measuring trackers are necessary in this case. Commercial hardware and software tools are widely available. AR performs four basic tasks, and its output is available in a usable form as follows [Blasko 2019]:

1. Scene capture - the main essence is that the reality that could be augmented must be captured using a recording device such as, e.g., a camera that can "see through or inside".
2. Scene identification - the second AR functionality is scene identification. The captured reality needs to be scanned and the exact location where the virtual content can be built needs to be defined. This location can be identified by markers (visual tags) or tracking technologies such as GPS, sensors, infrared or laser technologies.
3. Scene processing - subsequently, after the scene has been recognized and identified, it is necessary to determine the related virtual content, usually from the Internet or any database.
4. Scene visualization - in the last imaging phase, AR offers a image mix of the real environment and the virtual content imaging.

The development and implementation of AR software resources is significantly dependent on the development of suitable and resilient hardware platforms. The development of such hardware is influenced by technological progress in the field of computer processors, displays, sensors, speed of mobile internet, battery life, etc. Looking at the types of AR platforms currently available and at predictions of what awaits us in the medium term, the following suitable hardware devices can be found for AR today:

- handheld devices and mobile AR devices,
- static AR systems,
- spatial AR systems (SAR),
- head-mounted displays (HMD),
- smart goggles,
- smart lenses,
- smart devices.

The most basic components for creating AR applications include the combination of a real environment and virtual objects, as well as 3D writing and real-time interaction. Over the last few years, various algorithms and systems have been developed to solve tracking and registration problems in AR. Using these algorithms, various software environments for working with AR have been developed, enabling the development of specific AR applications. Currently, several companies are developing AR-based applications, focusing on the entertainment industry, where they are developing various applications and games. Currently we can use two basic types of systems for AR recognition, based on the recognition of shapes, objects: the Marker-based system or the Markerless system [Microsoft 2020, Milgram 1995].

The marker-based system uses the marker as a reference point, which is placed in the real scene, and according to this marker, the AR device can determine its own position in the real environment [University of Exeter 2020]. The condition for localization is that the device must know the marker. The marker can be used in many ways, one of the possibilities is that after the AR device finds and reads the marker, a 3D object will be displayed instead of the marker or above the marker itself.

Markerless systems can recognize things without the need for markers, where those things had not been directly provided by the application in advance. This principle is much more difficult to implement, because the recognition algorithm of the AR device must identify patterns, colors, etc. in real time [Straka 2017]. For a system that does not use tag identification, it is necessary to implement an algorithm that recognizes the shape and surroundings. For example, if the algorithm is written to identify a car wheel in the environment, then the AR application will be able to recognize the wheels of all cars that are in the viewing angle of the application at any time without the algorithm containing all types of wheels in the application. However, this method of evaluating and inserting AR elements without a direct geometric connection with the real world uses a combination of other additional information, such as markers, for recognition, e.g., GPS, accelerometer, compass, shape recognition, diagrams, etc. [University of Exeter 2020].

### 4 THE PRINCIPLE OF HOW AUGMENTED REALITY OPERATES BASED ON THE MARKERS RECOGNITION

#### 4.1 Markers

Markers are images inserted via an image tracking tool. AR technology makes it possible to use any image as a marker. However, for representing 3D objects, some are more suitable than other.

A quality marker should have the following characteristics:

- reasonable size,
- many contrasting corners,
- non-repeating pattern,
- sufficient difference in combination with other markers.

The image tracker is best suited for use on contrasting and more textured images. It is recommended to apply a mark containing a lot of details - not bold or block patterns.

It is not enough for the image tracker to find a file corresponding to the area between the marker and the scene being shot from the camera, it needs to find the correct geometric relationship between the two. The application of a marker with a well-

recognizable shape has diminished chance of making a false detection. However, if such patterns are repeated on the marker or they feature similar sections, they are not suitable for use. Similar patterns in different places in the image will be interchanged, making it impossible to tell where the marker is. The marker is also more difficult to trace in more demanding conditions. The best way to select a marker is to use one that has large contrast differences, and its shape ensures easy establishment of the object's position.

The position of a marker is expressed mathematically and refers to its location and orientation. The position of the camera represents its location and orientation in the coordination system and can be expressed by three coordinates of translational motion (x, y, z) and orientation under three angles of rotation (α, β, γ).

#### 4.2 Camera transformation

The mathematical expression of the T transformation between the camera and the marker is determined by the following relation:

$$x = TX \tag{1}$$

Where X is a point in the world coordinate system, x is its projection in ideal image coordinates and T is the camera transformation matrix. The T transformation consists of the translation vector t and of the rotation matrix R, which can be expressed in the form of a matrix [Siltanen 2012]:

$$x = [R/t]X \tag{2}$$

In homogeneous coordinates, this equation has the form of [Siltanen 2012]:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} r_1 & r_2 & r_3 & t_x \\ r_4 & r_5 & r_6 & t_y \\ r_7 & r_8 & r_9 & t_z \\ 0 & 0 & 0 & 1 \end{bmatrix} * \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix} \tag{3}$$

The rotation matrix has three free parameters (α, β, γ), which define its nine elements. The translation vector also has three parameters, so the matrix represents six free parameters. The marker tracking system must resolve the camera matrix for each frame each time it detects a marker.

#### 4.3 Optical distortion and camera calibration matrix

The camera's physical properties define how the image is finally processed and displayed on the camera's image sensor. Ideally, no other physical properties of the camera enter the image process during the image processing by the camera. Thus, the image is created in the plane z = f, where f is the focal length of the camera. A certain distortion, shifting occurs in real cameras due to manufacturing errors (e.g., the skewing of the image sensor). A frequent way is to present the camera mathematically as the (internal) calibration matrix of the camera K. This is a mapping between the ideal image coordinates and the camera, where the pixel coordinates  $x_{pix}=Kx_c$  are observed [Siltanen 2012, Weng 1992].

$$\begin{pmatrix} x_{pix} \\ y_{pix} \\ 1 \end{pmatrix} = \begin{bmatrix} f & s & p_x & 0 \\ 0 & f & p_y & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} * \begin{pmatrix} x_c \\ y_c \\ z_c \end{pmatrix} \tag{4}$$

A real camera can cause consistent geometric errors and distortion. This is due to lens imperfections. In most current cameras, the pixels are square, the columns and rows are straight. This means that in the camera matrix s = 0 and  $f_x=f_y$  [Siltanen 2012].

$$K = \begin{bmatrix} f & s & p_x & 0 \\ 0 & f & p_y & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \tag{5}$$

In this case, the distortion can be modelled after the internal transformation of the camera, which means that the camera matrix converts the ideal image coordinates into camera coordinates and the distortion function converts the camera coordinates into pixel coordinates [Siltanen 2012].

$$D \left( \begin{bmatrix} x_c \\ y_c \end{bmatrix} \right) = \begin{bmatrix} x_{pix} \\ y_{pix} \end{bmatrix} \tag{6}$$

$$D^{-1} \left( \begin{bmatrix} x \\ y \end{bmatrix} \right) = \begin{bmatrix} x_c \\ y_c \end{bmatrix} \tag{7}$$

The inverse distortion function of the  $D^{-1}$  non deformation function cancels the pixel coordinates in the camera coordinates. AR applications may use a separate calibration tool, or they must run the calibration process separately from the application. The pixel coordinates are first transformed into camera coordinates and then drawn [Siltanen 2012]:

$$K^{-1}D^{-1} \left( \begin{bmatrix} x_{pix} \\ y_{pix} \end{bmatrix} \right) = K^{-1} \left( \begin{bmatrix} x_c \\ y_c \end{bmatrix} \right) = \begin{bmatrix} x \\ y \end{bmatrix} \tag{8}$$

Ideal coordinates can be transformed into world coordinates and vice versa. Finally, the relationship between the world X coordinates and the observed  $x_{pix}$  image coordinates can be expressed as [Siltanen 2012]:

$$\begin{bmatrix} x_{pix} \\ y_{pix} \end{bmatrix} = D \left( KT \begin{bmatrix} x \\ y \\ z \end{bmatrix} \right) \tag{9}$$

#### 4.4 Position calculation

For most modern cameras, it is assumed that the distortion can be separated from the camera model. The points in the undistorted coordinates of the camera are marked as x, the corresponding points in the world coordinates are marked with X. Marker detection provides four points in the image coordinates  $x_1, \dots, x_4$ . For each corner point  $x_i$ , where  $i = 1, 2, 3, 4$ , [Siltanen 2012] the following applies [Siltanen 2012]:

$$x_i = KTX_i \tag{10}$$

This formula can be rewritten as follows [Siltanen 2012]:

$$\begin{pmatrix} x_i \\ y_i \\ 1 \end{pmatrix} = \begin{bmatrix} f & 0 & p_x & 0 \\ 0 & f & p_y & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} r_1 & r_2 & r_3 & t_x \\ r_4 & r_5 & r_6 & t_y \\ r_7 & r_8 & r_9 & t_z \\ 0 & 0 & 0 & 1 \end{bmatrix} * \begin{bmatrix} X_i \\ Y_i \\ Z_i \\ 1 \end{bmatrix} \tag{11}$$

After multiplying  $KT = M$ , the equation gets the form of [Siltanen 2012]:

$$\begin{bmatrix} x_i \\ y_i \\ 1 \end{bmatrix} = \begin{bmatrix} m_1 & m_2 & m_3 & m_4 \\ m_5 & m_6 & m_7 & m_8 \\ m_9 & m_{10} & m_{11} & m_{12} \end{bmatrix} * \begin{bmatrix} X_i \\ Y_i \\ Z_i \\ 1 \end{bmatrix} \tag{12}$$

The actual location of each corner point in world coordinates is known. A commonly used approach to solving the transformation matrix are methods for calculating the initial position estimate, e.g., direct linear transformation. Thus, the world coordinate X is exchanged for the image plane using the estimated transformation matrix  $\hat{M}$  of the projected point  $\hat{x}$  [Siltanen 2012]:

$$\hat{x} = \hat{M}X \tag{13}$$

The transformation matrix can be solved by finding a matrix that minimizes the projection error  $\|x - \hat{x}\|$  [Siltanen 2012]:

$$err = \frac{1}{4} \sum_{i=1,2,3,4} \{ (x_i - \hat{x}_i)^2 + (y_i - \hat{y}_i)^2 \} \tag{14}$$

## 5 CREATING AN AUGMENTED REALITY APPLICATION

The application environment in which the mobile application was created is UNITY 3D. The Vuforia Library allows Unity developers to create AR applications. It supports devices on Android and iOS platforms and allows applications to overlay physical objects with digital content. Digital models added to AR scenes were created in the PTC CREO system and are saved in \*.obj format.

### 5.1 Creation of Markers

To create a marker a registration on the Vuforia library manufacturer's website is needed. A new database will be created in the Tagger Manager item, where new markers can be registered subsequently. As a marker, the \*.jpg or \*.png file format is applicable, with the support for 8-bit black and white and 24-bit color format. The width of the marker is set in units of the AR content scene. In this project, it is set to 0.15. Once uploaded to the database, the marker is rated according to how well recognizable it is. Fig. 2 shows the recognition of a simple marker.

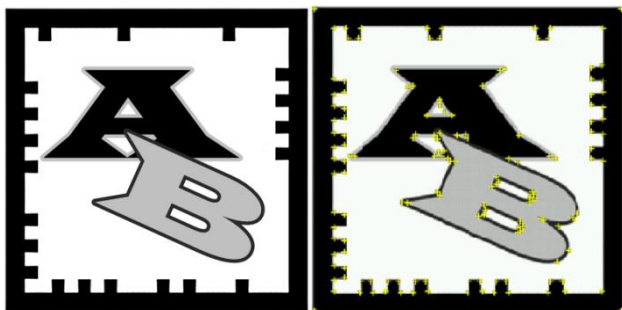


Figure 2. Example of a correct marker usage

For drawing dimensions of A3 format and larger, it is advantageous to use the whole drawing as a marker, as ImageTracking is limited by the visibility of the marker, so in this case one marker in the drawing is not enough. The edges of the drawing were highlighted because without them, scanning was unstable, and the model could fall out of the image or change its position. Fig. 3 shows a drawing that the application scans as a marker.

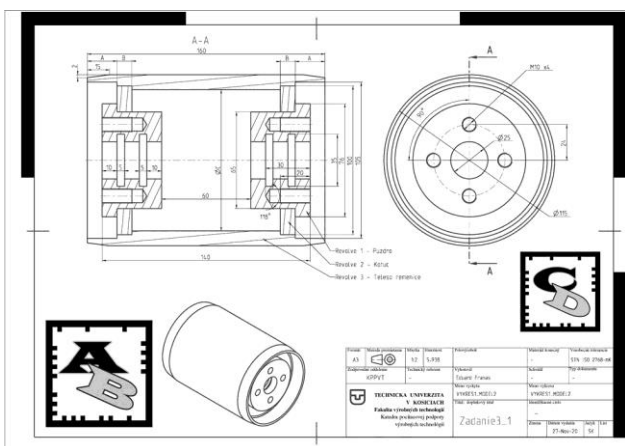


Figure 3. Setting the drawing as a marker

Fig. 4 shows an example of the recognition of points in a marker, with a significant difference in the number of points compared to a simpler marker. The advantage of using such marker is an easier model positioning, as the views shown in the drawing documentation are visible in the scene. Using a simpler marker would require more complex adjustment of model positions. Scanning of such marker proved to be stable even when viewed from a greater distance.

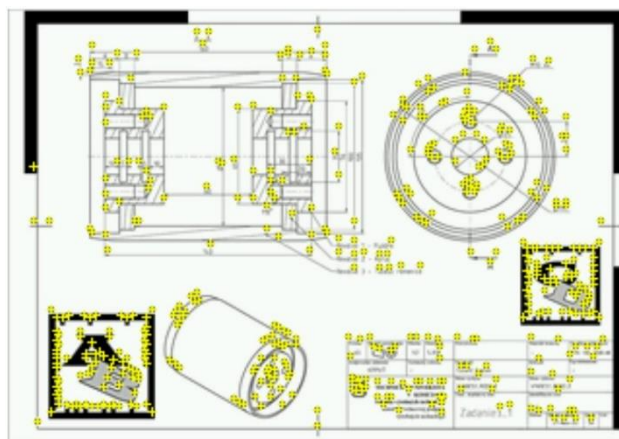


Figure 4. Identification of points in the drawing marker

### 5.2 AR application

An application that uses the AR function can be created without the main menu, if it is sufficient to use only one button to turn off the application and replace the monitored object. However, if multiple scenes are planned to be used, a user menu application is desirable (Fig. 5). The Unity program module is used for simple menu design. A new menu window will be created next to the displayed scene and you can switch between them at any time. Unity Samples: UI was used for a specific application. The module is imported similarly to the Vuforia library. In the Assets - MainMenu - Models - Prefabs folder, a GameObject named SF Scene Elements is selected and then it is moved to the Main Menu scene. It contains a predefined camera, background and Particle System.



Figure 5. Scene with a displayed model

The created marker is added to the scene by inserting an ImageTarget object. To select a marker, it is necessary to download the database from the created account and import the content into the project. Models are inserted into the object via ImageTarget, and their position is displayed in the program scene window. Important parameters are the model's position, rotation, size and texture. To display basic information, buttons with functions are added to the scene, such as part information, rotation and change of position in the X, Y, Z direction (Fig.6). The application runs on a mobile phone, with a built-in camera. The marker is displayed in the drawing's lower left corner. The model is positioned so that it appears above the view of the part in the drawing.



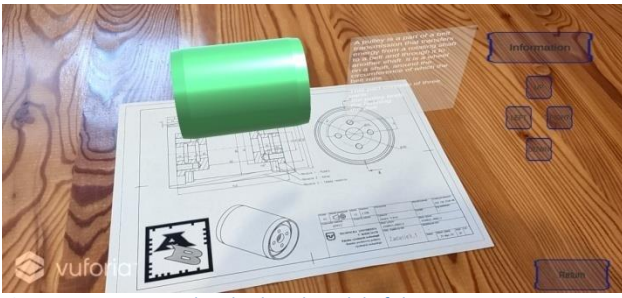


Figure 6. AR scene with a displayed model of the part

A different model is displayed with a change of the marker. This represents the part's cross-section with the maximum part dimensions (Fig. 7). To change the part model and to keep a single marker, it is necessary to create a new scene and then assign a program script to the button, through which the scene with a new digital model of the part will open.



Figure 7. Display of the scene with the part's cross-section

It is possible to display several models representing the part's cross-section or individual views of the drawing documentation in one scene. Fig. 8 shows models displayed above each view from the drawing. The drawing itself is used here as a marker. Additional markers, replacing virtual buttons, may be added to the drawing. The buttons are activated by covering the marker with your hands, for example. The advantage of using them is more free space on the display, which allows to have different controls in each drawing.



Figure 8. A scene showing multiple models of a specific part

### 5.3 Video in the AR environment

AR can be used as a tool to overlay real-world images with virtual content. The application enables, e.g., playing the instructions for modeling a part in the PTC CREO program via AR. The scene is created by adding a marker-sized (Fig. 9) area in the ImageTarget object. To be able to play the video, a new Video Player script needs to be added to the desktop and move the video being played to the Video Clip folder.



Figure 9. AR scene with a displayed model of the part

The video plays automatically after the appropriate marker has been loaded (Fig.10). You can add buttons to the scene, as well as elements for controlling the video (pause or start another video).

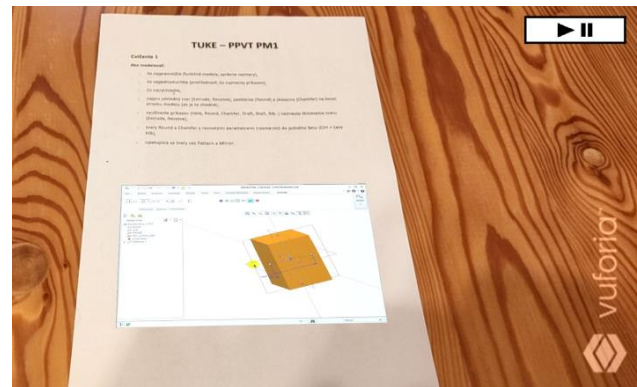


Figure 10. A scene with a Video playing

## 6 CONCLUSION

The paper describes the application of augmented reality tools to create an auxiliary interactive tool in the field of design. To mediate it, an application with AR operation based on marker tracking has been designed. Through the created application, it is possible to display the model of a part, the basic description of the part and to make available a video with instructions how to design a 3D model of the part in the environment of the PTC Creo. Two types of markers have been used in the application. A simpler AB marker, which it is more advantageous to apply to smaller dimensions of the drawing (A4 format), or for displaying the part outside the drawing, only above the mark itself. For larger drawing dimensions, it is recommended the entire drawing be scanned as a marker. This will ensure its better identification. The application was tested on a Samsung Galaxy Note 9 mobile device, where no significant problems with its functionality have been recorded. However, poorer identification of markers in poor lighting conditions can be a problem. The application is intended for production machine designers and operators. It helps to better present the digital model of the manufactured part, as it is displayed above the drawing documentation. The size of the model can be modified using the buttons displayed on the screen. Another possible use of the created application in the mechanical engineering production itself can be, for example, the display of the CNC machine tool model above the marker, which is glued to the tool holder, with catalog data for the given tool type.

The ability of augmented reality to provide high intuitive control and relatively simple practical implementation surpassed virtual reality in growth and use, which has been one of the most significant impacts of the late 1990s.

Augmented reality has found its place in mobile devices with the advent of smartphones. The application of augmented reality in the field of production and design is a relatively new sphere of its use. This is largely due to the consequence of the required accuracy in the application of augmented reality in these areas and the good alignment with traditional practices.

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