ISSN: 0974-5823 Vol. 6 No. 3 December, 2021

International Journal of Mechanical Engineering

INTUITIVE ASSISTANCE OF INDUSTRIAL AUGMENTED REALITY IN SERVICE AND TRAINING - A CASE STUDY OF INTERACTIVE ENVIRONMENT FOR EXPLODED VIEW OF TWO-WHEELER DISC BRAKE ASSEMBLY

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***Abstract*—** Technology has evolved in every aspect of the dimensions of any activity concerned. With minimization of time and process errors turned imperative to be accomplished for the upward growth of the industries, the concept of industrial augmented reality (IAR) promises better and desirable consequence. With the proposed technology emerging big, it has the potential to change the environment of training and maintenance area completely. Manual errors due to lack of expertise, misunderstanding of the instructions, deflection of concentration, etc can be drastically reduced along with no requirement for large manpower in the particular sectors. To showcase our idea and the capability of industrial augmented reality, we have used the concept in the display of user-interactive exploded view animation of a two – wheeler disc brake assembly. This paper reflects our predicted prospect of augmented reality assisting humans in numerous ways apart from product development line such as service, maintenance, training, education and even marketing.

***Index Terms*—** Augmented Reality, human – computer interaction, disc brake assembly

1. INTRODUCTION

With technology improving, demands increase. Conventional manufacturing and maintenance methods can no longer meet the demands [1]. Digital manufacturing emerged with the capability of meeting increasing demands, distinct customer preferences, quality in competitive market and fluctuating trends [1]. Mass production is being replaced by mass customization to reduce the lead time and increase the productivity simultaneously [2]. The contribution of computational intelligence has been indispensable in today's age.

A. INDUSTRY 4.0

Originated in Germany and introduced in 2011, fourth industrial revolution is currently the prime objective of the industrial universe [3-5]. The fourth industrial revolution, also known as industry 4.0 emerged to implement intelligent technologies from product design to manufacture [6]. The term intelligent technologies include Artificial Intelligence (AI), robotics, cloud-computing, Internet of Things (IoT), Extended Reality (XR), Additive Manufacturing (AI), Machine Learning (ML), Data Analytics (DA) and so on [6,7]. The implemented concept of automation assists humans in product design, simulation, prototyping, manufacture, maintenance, service and in market also. With this great potential, industry 4.0 can overcome many social and economic problems of conventional engineering methodologies while complying sustainability [6].

B. HUMAN – COMPUTER INTERACTION (HCI)

Human – computer interaction is a concept in which collaboration of human intelligence and computational intelligence is implemented in any process to achieve quicker design, simulation, visualization and guidance thereby increasing productivity [8]. Introduced in computer processes in 1970s, the paradigm of human – computer interaction extended its dominance in biology, medicine, sociology, business, manufacturing, economics and many more [8].

C. EXTENDED REALITY (XR)

Extended Reality (XR) is a collective term for the technology that makes any engineering process easier by assisting designers in exploring complex possibilities of design and simulation, guiding workers in manufacturing and maintenance through fabrication and blending of real and virtual environment for better understanding of the target component or method [9]. Extended reality includes Augmented Reality (AR), Virtual Reality (VR) and Mixed Reality (MR) [9]. Instigating a revolution in engineering fields by incorporating new dimension in distinct processes, extended reality unfurled greater potential and options for viable outcomes [10]. They are extensively incorporated in almost every processes of automobile sector [10]. Extended Reality is particularly very much functional in customer attraction by bringing them into a virtual world where they can tour every features of the model interactively [10].

In our research, we emphasize the incorporation of augmented reality in maintenance and serviceability aspect. Assembly and disassembly of disc brake system is carried out blending augmented reality with the intention of service – based assistance.

2. RELATED PARADIGMS REVIEW

In this session, we will explore few related concepts that share similar foundational approach of augmented reality and other paradigms involving the blending of digital intelligence in maintenance and service of components to get a better understanding on the focus of our research.

A. VIRTUAL REALITY (VR)

Ivan Sutherland in 1960s described virtual reality for the first time as "a window which opens the door for virtual world where the user can experience it as if it is looked, heard and sensed real in terms of interaction" [11-13]. Virtual reality does this by constructing an artificial but realistic and interactive environment with the help of dedicated software and devices where the user can interconnect with it opening the doors for data transformation in a more powerful and effective way [12,14]. Three qualities are required for a virtual reality system to be reliable [15]. They are 'immersion experience', 'stereoscopic vision' and 'motion capture' [15]. The virtual reality technology has now branched itself into numerous distinctive fields like automobile, robotics, machinery, science, gaming, process planning, medicine, surgery, biology, educational training, maintenance and construction assisting in almost all stages of processes involved in them [16]. Mentioning specifically, virtual reality aids in displaying the most optimal plan of any manufacturing process to prevent erroneous progress yielding undesirable results [17]. This technology is also employed in training programmes to break the barriers of expertise level of handling in any processes, exploiting the users to practice methods in a safe environment and exposing them deep through each stage of the processes resulting in better knowledge gain and experience [17].

B. HAPTICS

The concept of haptics is the foundational approach of extended reality. The term 'haptic' was derived from a Greek word 'haptesthai' meaning 'touch' [18]. Haptics is a technology that makes use of the sensory touch of user and transmit feedback in the form of vibration or force through piezo-electric actuators [18,19]. Haptics has been conventionally used in phones today. In general, it receives the touch sense of user as input to drive any programmed operation intuitively and provide control of the system remotely [18].

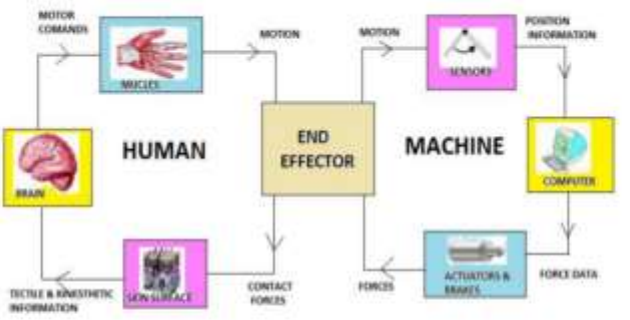

Fig. 1. Haptic interface [19,20]

Haptic interface operates based on two systems: Human system and Machine system as shown in fig. 1 [18-20]. The human system regulates the touch input respective for the desired operation while the machine system senses the input and establishes transmission of data with the target virtual object [18-20]. Both systems possess sensors, processors and actuators [18-20]. Nerve receptors, brain and muscles act as sensors, processors and actuator respectively in case of human system [18]. The end effector is an intuitive haptic mechanism which contains many sensors that receives touch input and behaviour of the user and transmit the data to the computer where the data is analysed for the operation that is to be carried out and then regulates the actuator accordingly which signals the acknowledgement of the command through feedback force or vibration felt by the user [18-20].

C. DESIGN FOR DISASSEMBLY (DfD)

With engineering processes and handling techniques improving, the production rate has to be increased in this competitive age. The manufacturers must introduce quality products with better lifetime while increasing material and cost efficiency [21]. It not only depends on manufacturing but also the maintenance and serviceability of the product [21-23]. Design for disassembly is a technique that is introduced to make the disassembly of any product uncomplicated to achieve effortless maintenance, serviceability, repeatability, repair and recuperation in order to reduce material wastage and increase end-of-life of the product [21]. It addresses the limitations of conventional product development phases by enabling flexibility in development, shorter lead time and reduced production cost [21,23].

3. AUGMENTED REALITY (AR)

Industrial Augmented Reality (IAR) is one of the salient aspects of the fourth industrial revolution to enhance cognitive capability in any process [24,25]. The paradigm was formulated in 1960s by Ivan Sutherland [24]. The technology was not well-known due to deficit in affordability for dedicated AR devices [26]. On the contrary, today, mobile phones with specialized and powerful mechanisms are available resulting in widespread popularity of AR [26]. Augmented reality is a branch of virtual reality [27]. The primary principle of augmented reality is overlaying artificially created virtual environment with real environment for powering the process [27]. However, it does not consider the immersion effect of the user as in virtual reality [27].

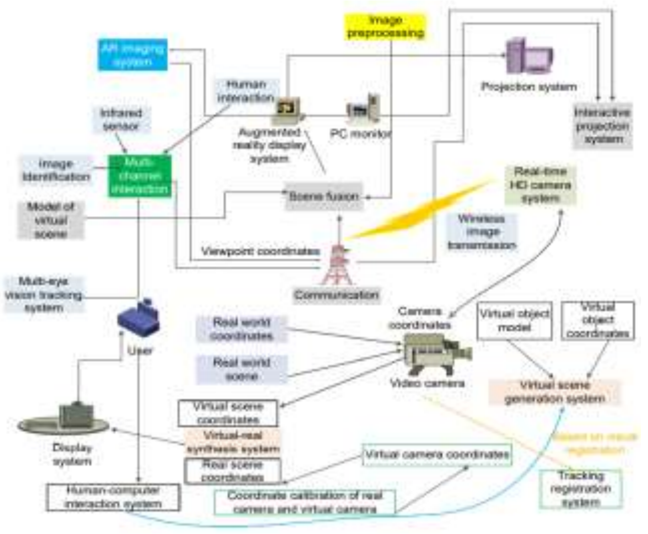

Fig. 2. Configuration of augmented reality system [27]

The configuration of an augmented reality system consisting of complex interconnection of dedicated hardware and software [27] operating together is shown in fig. 2. The data of images captured in real environment and objects framed to be incorporated in virtual environment are transmitted to the output device [27]. The hardware network of the augmented virtuality system mainly comprises of four mechanisms: input devices, sensors, processors and displays [28]. Input devices are implemented with either voice recognition, gesture recognition or haptic system to instruct the software to perform the desired operation [28]. In some applications, sensors incorporated in devices like glove, pointer, stylus, joystick etc provides the input and can be considered as input device [29]. Sensors have three main functions. They are used for tracking the position of viewer [29]. The position includes both location and orientation [29]. They gather data on components constructed in both real and virtual environments and transfer to the software [29]. As we have seen above, they, sometime, act as an input device to formulate user input data [29].

The tracking mechanisms of sensors follows four main categories based on the medium used for operation: magnetic field tracking, optical tracking, acoustic tracking and inertial tracking [27,28]. Magnetic field tracking mechanism consists of signal receivers, transmitters and control components [27, 28]. The signal transmitter creates a magnetic field while the signal receiver receives it. The control component measures the strength of the receiver signal to calibrate the location and orientation of the viewer [27,28]. Optical tracking mechanism employs a photosensitive sensor device which transmits optic signal corresponding to the image under focus [27]. The position can be determined by analysing the signal [27,28]. This mechanism is applied in indoor applications [28]. Acoustic tracking, similar to optical tracking, uses ultrasound as the medium for tracking [27,28]. Acoustic device like microphone sends ultrasound waves for the object under focus, the signal is analysed and the position is resolved [27,28]. Inertial tracking mechanism applies gyroscope and accelerometer to determine the angular velocity and acceleration of the target [27]. These micro devices use imaginary coordinate system relative to a foreknown starting coordinate to establish the position [27,28]. The elaborate operation of the four tracking systems, their advantages and disadvantages are given in [27][28].

The processor is the central part of the augmented reality configuration. The main function of processor is to receive inputs from sensors, analyse using application program embedded as a software and transmit output signal to display devices or output devices as commands to drive the operation [28,29]. Generally, they use microprocessors for central unit and graphic processor units, the latter being used to construct the three-dimensional objects for the virtual environment [28]. The architecture of the processor may range from simple handheld machines like smartphones and tablets to larger and powerful machines [29]. The processor must be robust enough to analyse every data in real time, process them to align the captured images corresponding to the position without any lag or delay which makes the system flawed.

The display mechanism receives the output signal from the processors and displays the constructed structure of real and virtual environment [27]. The system must have a superior quality to make the user perceive better which determines the overall grade of the system [27]. The scene synthesizer aligns the data representing the images from real environment and the graphics from virtual environment [27]. The final result is what the viewer perceives as a blend of real and virtual environment [27]. The display system varies as per the type of sensory perception such as visual displays, audio displays, haptic displays, stereo displays etc [28].

A. AUGMENTED REALITY IN MAINTENANCE AND TRAINING

Adopting to new technologies not only increase the productivity of a company but also provides a betterment among their competitors globally. Automobile industry have always adopted to technological advancements to evolve as a viable sector [30]. Augmented reality is well received by the industry due to its versatile capability in resolving advanced solutions [30]. It is mostly used for marketing in the mass customization, allowing the customers to lively interact with the model and customize for themselves [10]. AR is also incorporated in driver assistance system guiding the drivers on traffic and obstacles in their way [10]. It helps in reducing accident possibilities by displaying the lanes and oncoming vehicles, thereby contributing to road safety [10]. The application of augmented reality is not limited to marketing, it also assists humans in product design, simulation, visualization, manufacturing, inspection, maintenance, service, repair, diagnostics, logistics and training [30]. The contribution of the technology in industrial field is described in figure 3.

The maintenance assistance of augmented reality will produce better outcome than paper-based manual and monitor instructions by eliminating human errors to a larger extent [31]. Maintenance denotes disassembling the component, identify the flaws, rectify them and assemble back. The training guidance by augmented reality for the labour yields improved worker productivity and saves a lot of time by implementing innovative training procedures and building virtual safe working space that can be received by the workers much better [24]. Before the application of augmented reality in the above aspects, the trainer has to motivate the workers and ensure a surrounding of comfortability [32]. Then, the trainer has to showcase the operation in a step-by-step manner while emphasizing on the principles that influence the system directly or indirectly [32]. After the instructions, the workers have to try out the operation under the supervision of trainer who rectifies their flaws, if occurred [32]. Finally, when the worker has gained knowledge on the operation, both functionally and conceptually, the trainer has to supervise the workers on a regular basis to consolidate the productivity of the individual [32]. This procedure has been in the practice traditionally. Not every time the trainer is expected to be present. Not every time the worker does the operation flawlessly. Hence, augmented reality is of use here. Studies showed that more than one third of the users aged above 14 find video-based tutorials easier to understand than paper-based manuals for activities in their daily life [33]. Bringing the video information into virtual world and mapping it onto real world will have an indispensable impact on the operational knowledge and perspective of the users [31]. And also, the global uprise in the technological features used in daily life necessitates the extended reality manuals for faster adoptions [31].

A successful diagnostic operation of a mechanical component depends on realizing the issue and repairing accurately [34]. The manuals will be available either as paper or video manuals [34]. Paying attention towards both the manual and the component turns laborious, especially when the understandability of the instructions is poor [34]. Hence, augmented reality provides real-time clear service instructions for the user in his/her view without any loss of information [34]. This reduces the service time and user effort assisting ergonomically [34]. The training and service assistance features of augmented reality is classified as embodiment and virtual feature [24]. Embodiment system provides enhanced immersion with the use of hardware like HMD [24]. Visual fixture involves overlaying of instructional objects over the real environment [24]. Further, the recent popularity gain among marker-less tracking system due to cost-effectiveness, efficiency and unnecessary marker positioning led users employ it to any operation regardless of the structure and environment [35].

The contribution of augmented reality in maintenance and servicing led people with even less expertise to participate in operations, reducing the learning time and effort while providing a safe environment [30]. The system can also be integrated with telepresence system to effectively interact with the worker aiding with unexpected issues [26]. This could have a considerable positive effect on the industrial environments and the user mindset by increasing the component life and outcomes [36]. Organizing the maintenance, service and training instructions to blend with augmented reality necessitates a wide and deep knowledge on the concepts involved in the procedure, mapping the instructions into virtual display without misorientation and aligning real and virtual world accurately irrespective of the user's field of view and environment [37].

Overall, the incorporation of augmented reality in operational assistance enhances construction of database of information containing distinct components and their instructions, allows inexperienced users to perform desired tasks without outside guidance, enables exposure to updated tactics and instructions, provides a safe environment for dangerous tasks and aids in better and clearer knowledge gain than gained through other manuals [38]. The introduction of augmented reality yielded cost reduction of 25% and increased performance efficiency of 30% [38]. The growth rate of industrial augmented reality in the global market annually is estimated around 74% in 2018 to 2025 while the global market of $76 billion is expected by 2025 [39].

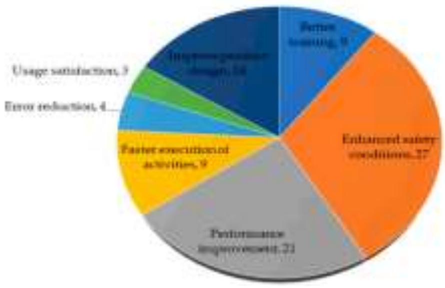

Fig. 3. Benefits of augmented reality in industry [30]

B. APPROACHES IN AUGMENTED REALITY

In this section, we will look into other similar approaches carried out. In recent years, applications of augmented reality in maintenance and training have increased due to the betterment compared to its predecessors. *Werrlich* et al. introduced an augmented reality guidance mechanism for engine assembly line [32]. *Ceruti* et al. developed an augmented reality support system incorporated with reverse engineering technologies that identifies the faulty components, scan and gather the diagnostic data to print the component using additive manufacturing methodologies [40]. *Freddi* et al. suggested an AR – assisted guidance technique for disassembly of tailstock [41]. *He* et al. developed an augmented reality based multi-sensory annotation technology to guide users in lubrication process of hydraulic jack [42]. *Mourtzis* et al. introduced an augmented reality guidance to enhance quicker communication between shop operators and maintenance personnel [43]. *Sarupuri* et al. introduced an augmented reality assistance tool to guide forklift operation [44]. *Fotios* et al. presented a mobile augmented reality-based guidance tool for faster maintenance of air-conditioning compressor used in car [45]. *Uva* et al. designed a spatial augmented reality system for assisting in camshaft inspection of Honda CBR 600 motorbike engine [46]. Caudell and Mizell proposed an augmented reality assistance system to aid the workers in assembly of Boeing aircraft resulting in 20 to 50% wiring assembly performance [47]. Reiners et al. described an augmented reality assistance tool to perform assembly of door locks in cars [48].

In future, augmented reality eliminates the need for physical presence of trainers and supervisors completely by contributing complete and real-time guidance in versatile fields while improving efficiency of both man and the machines.

C. OBJECT RECOGNITION BY AUGMENTED REALITY

There is more than one way for augmented reality image or object recognition. Visual markers are one such type. Markers aid in identifying the target images or objects which are focused by the user [49]. Markers may either be an image that is paper-based or digital or a real-world object. They have the potential for triggering the augmented reality operation [49]. Once the viewer screen focuses the dedicated marker, the augmented reality system kicks in and commences the predetermined program [49].

Our approach is based on model targets. To enable a model target, either a 3D model or a three-dimensional scan of the target object is needed. When the model is analysed by the software that runs augmented reality, the camera that the user handles scan for the required image on the screen. Once the object or image feature that matches with the input data, it activates the whole sequence of augmented reality process.

4. AUGMENTED REALITY IN DISC BRAKE

A. APPLICATION OF THE COMPONENT

The disc brake system consists of brake disc, hub, brake caliper and a pair of brake pads. The disc is connected to the wheel though the hub. During braking, the disc is subjected to high heat and friction. Therefore, the disc is designed with vents and grooves for the convectional purpose. Brake calipers are fixed around the brake disc and aids in stopping the rotating brake disc via brake pads. The brake pads housed inside the brake caliper contacts against the disc to reduce its speed. When the brake lever is pressed, the hydraulic fluid passes through hoses and pushes the piston located inside the brake caliper. The piston pushes the brake pads and thus the brake disc is stopped.

B. OBJECTIVE OF OUR APPROACH

The primary focus of our research is to display a two-wheeler disc brake in exploded view showcasing every parts of the assembly separately while enabling the feature of user interaction through the digital module. Our focus is emphasized on implementing the augmented reality in training phases. We have exemplified the exploded animation of disc brake for the application of augmented reality in such stages of operations. Through this, the duration of training for service technicians significantly reduces through augmented reality, the manual errors can be avoided or at least reduced and also by employing augmented reality, it is possible to provide the customers a better understanding of the product.

C. CAD MODELLING

Fig. 4. Model Reference – Honda Shine Brake disc

The disc brake model is designed in Autodesk Fusion 360. The applied model is inspired from the disc brake assembly of Honda Shine. Initiating the design with 2D model, every component is designed as per the assembly.

PARTS	FUNCTIONS
Brake disc (1)	Stops the wheel during braking as it is connected with the hub.
Brake caliper (1)	Houses the pistons and pads
Brake pads (2)	Stops the disc rotation by contacting it
Brake pistons (2)	Pushes the pads to contact driven by hydraulic fluid
Caliper mounting bracket (1)	Supports brake caliper
Pins and nut	For holding components

Table 1. Components designed

The disc brake model is designed true to the original dimensions of the disc brake of Honda Shine. You can witness the reference of the model we designed from figure 4 while the above table 1 represents the parts we included in design. The final model designed is described in fig. 5.

Fig. 5. The designed brake disc model

D. TOOLS USED

The complete operation for embedding augmented reality in disc brake exploding view required Fusion 360 for CAD model and Unity, PTC model target generator and PTC Vuforia Engine Unity pack for fabricating augmented reality environment and visual studio for editing the sequence code.

E. IMPLEMENTATION OF AUGMENTED REALITY

The CAD model designed is exported in '.obj' format. Then, we import the Vuforia engine in 'json' format into the Unity platform. Only the AR camera is included and the main camera is excluded because we intended to exhibit the exploded animation and not the 3-dimensions of each component. This work is carried out with 2 'scenes' in Unity. One for animation of brake disc and the other one for exploding the components of brake disc with enabled user interaction through digital monitor. The model target created using PTC Vuforia model target generator is imported into Unity and is added to the first scene. This model target houses the data of edges and curves necessary for recognition of the real-world object. The CAD file is imported in '.obj' format. The newly imported CAD file is then scaled to match the model target so as to ensure easy recognition. Figure 6 describes the guide view portrayed in Vuforia model target generator. Fig. 7 represents the actual image of the model target.

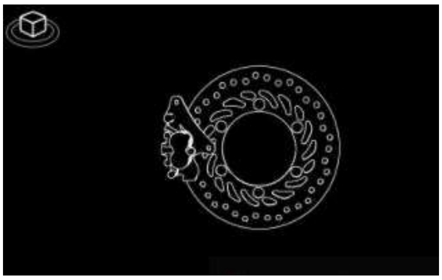

Fig. 6. Guide view from Vuforia model target generator (model target)

F. ANIMATION SCENE

The animation scene enables automatic exploded view animation sequence without the user interaction (fig. 7). Certain features were added in this animation scene canvas such as On/Off label, Play Animation, Pause Animation and Explore Drag 3D (Fig. 7).

On/Off label: For showing or hiding component names in the brake disc assembly. The labels travel along with the parts. Play Animation/Pause Animation: For pausing or resuming the exploding animation sequence. Once paused and resumed, the animation will tend to resume from the position at which it was frozen. Explore Drag 3D: For switching the scene from animation to user interaction.

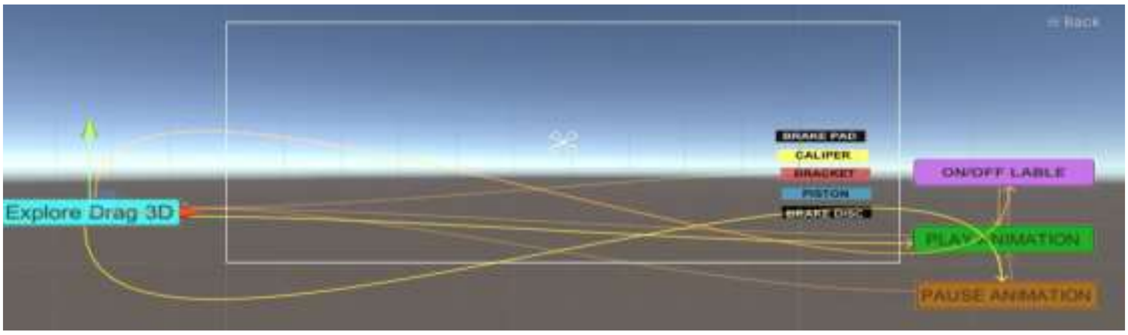

Fig. 7. Animation scene canvas

Fig. 8 shows the dope sheet of the animation pattern of the assembly. Dope sheet is a summarized sheet containing the data of how each part of the assembly is programmed to disassemble. In general, it covers the duration and the separation position with respect to three axes of the operation of each part.

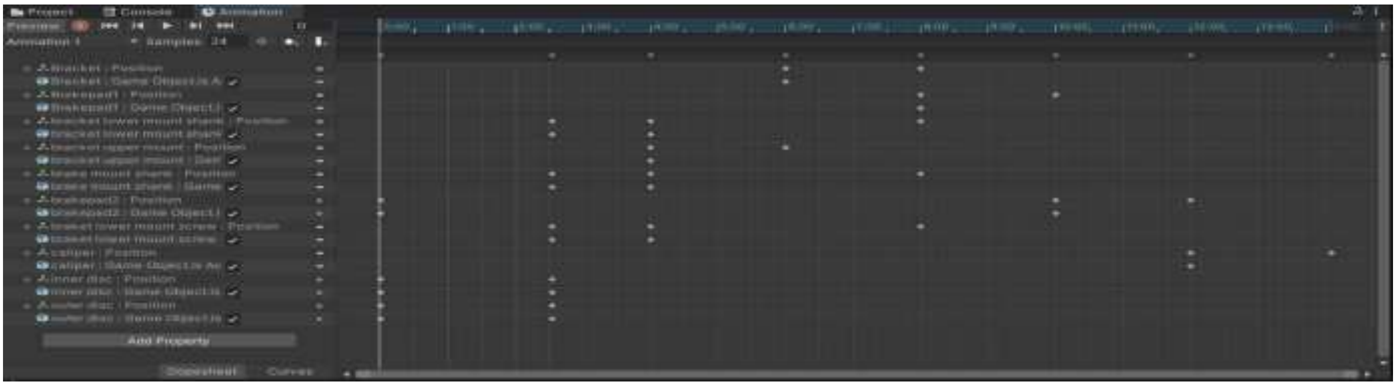

Fig. 8. Assembly Animation Dope Sheet

Fig. 9 represents the automatic exploded view animation programmed. Each part dismantles as per the dope sheet. The options are displayed for further convenience. When the play animation is enabled, the parts explode until the pause animation is pressed.

Fig 9. Exploded view in animation scene

Every feature appearing on the monitor works on the basis of program codes assigned. Figure 10 represents the program code used to enable play/pause animation feature. The type of program used in our project is C Sharp (C#).

As explained before, EXPLORE DRAG 3D feature is used for switching the scenes. Figure 11 represents the C# program code for the same. Similarly, programs are embedded for on/off label option.

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using UnityEngine.UI;

public class [illegible] : MonoBehaviour
{
    public Animator animator;
    public Transform my3DModel;
    public Transform MyPauseButton;

    // Use this for initialization
    void Start()
    {
        animator = my3DModel.GetComponent<Animator>();
    }

    public void playAnim()
    {
        animator.Play("Animation 1", -1, 0f);
    }

    public void pauseAnim()
    {
        animator.speed = 0;
        MyPauseButton.GetComponentInChildren<Text>().text = "RESUME";
        Button btn = MyPauseButton.GetComponent<Button>();
        btn.onClick.AddListener(resumeAnim);
    }

    void resumeAnim()
    {
        MyPauseButton.GetComponentInChildren<Text>().text = "PAUSE";
        animator.speed = 1;
        Button btn = MyPauseButton.GetComponent<Button>();
        btn.onClick.AddListener(pauseAnim);
    }
}
```

Fig. 10. Code for play/pause animation (disassembly)

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using UnityEngine.SceneManagement;

public class SceneSwitcher : MonoBehaviour
{
    public void playGame()
    {
        SceneManager.LoadScene(SceneManager.GetActiveScene().buildIndex + 1);
    }
    public void Back()
    {
        SceneManager.LoadScene(SceneManager.GetActiveScene().buildIndex - 1);
    }
}
```

Fig. 11. Code for switching between scenes

When the real-world object is recognized, it enables the users to interact with the parts. They can be dragged and located as per user's control. Similar to the previous interface, respective C sharp programs are embedded for dragging objects complying the user control, for scaling the parts up or down and for restarting the scene.

5. RESULTS AND DISCUSSIONS

Fig. 12 showcase the outcome of our work. The features ease the user needs. The disc brake is recognized by aligning the model target appearing on the digital screen with the target object and the recognition does not necessitate accurate alignment.

Fig. 12. User interaction – scaling up of a component (brake caliper)

Vuforia and Unity aided us through object recognition feature by model targeting. PTC Model Target Generator is used to create the model target of the disc brake feature. Vuforia had the option for tracking two-dimensional model targets [49]. Once the application was initiated and scanned for the target feature in the real world, it commences the tracking process. It requires the user to focus the target at a particular distance and angle. Hence the digital screen displays a silhouette of the target feature, i.e., brake disc to facilitate the tracking program. The image displayed is called guide views in Vuforia. Once the guide view almost matches with the target, the subsequent actions are activated for displaying the whole disc brake unit enabling added features for user interaction.

6. CONCLUSION

The disc brake disassembly and exploded view is exhibited with the incorporation of industrial augmented reality. With the increasing growth of augmented reality in industrial universe, it would yield significant outcomes if the technology was employed in training and maintenance sectors. Our attempt on the showcasing the exploded view of a two – wheeler disc brake corroborates the above statements. Better source and investment enable the introduction of various useful features and ergonomics in the field of our applications. Augmented reality facilitates the training processes in the long run yielding better impact from both workers and machineries. Hence, it would be prudent to apply the industrial augmented reality in training, maintenance and educational sectors in industries.

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