TRANSFORMING PAPER-BASED WORK INSTRUCTIONS INTO ANIMATED CAD SIMULATIONS WITH AI-GENERATED CAPTIONS

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ABSTRACT

Industrial documentation plays a vital role in guiding operators to perform their tasks correctly. These documents are clear, legible, and error-free to avoid any mistakes in the execution of operations.

However, using paper-based documentation, such as work instructions is expensive, prone to errors, challenging to manage, vulnerable to security breaches, and time-consuming. It also requires regular updates on physical documents due to new product requirements.

To improve efficiency and cost-effectiveness, a worker-centered system has been introduced the integration of animated Computer-Aided Design (CAD) simulations with Artificial Intelligence (AI)-generated captions. This system provides on-site instructions through various visual renderings created with CAD software.

The system has been tested for Pick-body Assembly and has shown significant improvements. It eliminates the need for paper-based work instructions, resulting in savings of approximately $8026.50 for companies. Additionally, it reduces assembly time by 16.4% and the number of errors by 62.5%.

1. 0 INTRODUCTION

Work instructions are step-by-step guides that provide clear details on how to perform a specific task. To have effective work instruction, they must meet certain criteria such as being credible, clear, accessible, and consistent. They play a crucial role in guiding individuals on how to carry out specific tasks efficiently. Traditionally, work instructions have been presented as printed papers placed on tables or boards next to the operator's workstation as shown in Fig. 1. This is called paper-based work instruction.

Fig. 1. Traditional work instruction is filed in a binder and placed on the workstation. Flip through the document and read it by the production technician during the assembly work process.

However, with advancements in technology, particularly Animated CAD Simulations with AI-generated captions, there is a significant opportunity to transform how work instructions are delivered. This technical paper explores the benefits and implications of transitioning from paper-based Work Instruction into Animated CAD Simulations with AI-generated captions.

In addition to improved visual representation and real-time guidance, transitioning to animated CAD simulations with AI-generated captions offers several practical benefits. For instance, it can streamline the updating process of work instructions. Instead of reprinting entire manuals whenever a change is necessary, digital simulations can be easily edited and updated, saving time and resources. This dynamic nature of CAD simulations allows organizations to adapt quickly to new procedures or technologies without significant disruptions.

1.1 Paper-Based Work Instruction

The use of paper can often make processes more complicated due to the various issues that come with it and as the production demand increases, the use of paper also increases, which has a significant cost value. The process of creating a paper file can be complex and involve many printing risks. A printed procedure can also be challenging to understand and to access the information, the operator needs to flip through the documents and search for what they need. This can make the task more complicated and waste time and energy. Moreover, this has the potential to lead to mistakes and standardization issues with even the most experienced employees, costing your company money and time, this is a waste of time. Time that could be better spent growing your business.

1.1.1 Cost of paper-based work instruction system

A business must increase its revenue without compromising its volume of production or sales. This requires a thorough analysis of the framework to ensure that there are no unnecessary expenses or entry points for additional charges. While paper-based document management processes have been in use for many years, they are no longer the most efficient and cost-effective way of handling manufacturing processes and test instruction documents.

Table 1. Machine Assembly production total cost expenses for manufacturing documents.

PRODUCT	MPI/ MTI (pcs)	TRV/ CON (pcs)	TOTAL PROCESSED MACHINE (pcs)	TOTAL	DOCUMENT PROCESSING TIME PER PAGE (mins.)	MANHOUR COST	COST/ PAGE	TOTAL COST
Test Handler 1	1257	129	81	11706	3	$2.00	$0.20	$3,511.80
Test Handler 2	930	110	2	1150	3	$2.00	$0.20	$345.00
PNP-Module	450	56	207	12042	3	$2.00	$0.20	$3,612.60
Test Handler 3	1419	146	3	1857	3	$2.00	$0.20	$557.10
TOTAL COST								**$8,026.50**

Product Test Handlers 1, 2, 3, and the pick-and-place (PNP) module are the machines that we're assembling. Manufacturing Process Instruction (MPI), Manufacturing Test Instruction (MTI), Travelers (TRV), & Configuration (CON) are the documents used in production during the assembly process.

In 2023, the production expenses for manufacturing documents related to machine mechanical assembly were over $8026.50 as shown in Table 1. For the calculations of manufacturing documents see Fig. 2.

$$= \left(\text{Total page} \times \text{Cost/Page}\right) + \left(\frac{(\text{Document Processing Time/page}) \times \text{Total page}}{60\ \text{mins.}}\right) \times \text{Manhour Cost}$$

Fig 2. The formula for calculating the total cost of Paper-based Work Instruction.

1.1.2 Updating paper-based work instructions: a waste of time and energy

Work instructions cannot remain frozen in time because they must adapt to the arrival of new factors: new standards, new tools, new processes, and new demands. Therefore, regular changes must be made to these operating procedures, which means that they must be updated each time. However, this is a serious problem when dealing with traditional paper-based media**.**

This means that all copies of the old versions (those that are not up to date) of the work instructions must be removed from circulation to ensure that no employee still uses them to do their job. The next step is to reprint all documents, and then to ensure that all operators have the updated documents after validation by the various personnel concerned (production manager, quality manager, and operators who may also be involved in these updates). All this mobilizes resources (material and human), energy, and time.

1.1.3 Difficulty in managing and securing documents

As corporate documentation must be archived, it is easy to imagine the volume of documents to be stored and managed as they accumulate. They require a dedicated space, with significant material resources (cupboards, filing cabinets, wear, and tear protection) and organizational resources.

Updating work instructions also poses a security and confidentiality issue. Security problems exist since any paper support is likely to be altered or even destroyed in the event of an accident, mishandling, or disaster. As far as confidentiality is concerned, there are concerns about possible data leaks to competitors, as paper documents can be hidden and misused.

Fig. 3. Shelves of Paper-Based Work Instruction or Manufacturing Process Instructions (MPI). Filed in a binder and displayed in the production area.

1.2 Animated CAD Simulation

One key advantage of animated CAD simulations is the enhancement of visual representation. Unlike traditional paper-based instructions, CAD simulations provide a more engaging and interactive way of presenting information. By leveraging 3D modeling and simulation techniques, users can visualize complex processes in a realistic environment, allowing for a better understanding of each step involved. This visual clarity can lead to improved comprehension and retention of information, ultimately enhancing the overall learning experience.

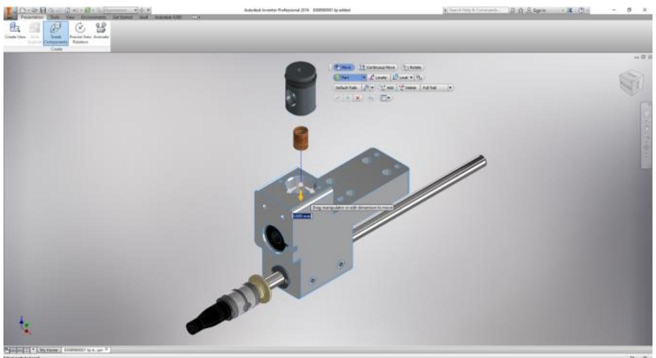

Fig. 4. Plotting and rendering an animation to animated CAD of Pick-Body mechanical assembly through Autodesk Inventor Software.

1.3 AI-Generated Captions

Integrating AI-generated captions further enriches the user experience by providing real-time guidance and context within the CAD simulations. AI algorithms can analyze the simulation data and automatically generate descriptive captions that accompany each process step. These captions can offer valuable insights, such as tips, warnings, or additional information, ensuring that users have all the necessary details to perform tasks accurately and safely.

Furthermore, using AI-generated captions can enhance accessibility for a diverse range of users. Individuals with different learning preferences can follow instructions more effectively by providing information in multiple formats, such as visual representations and textual descriptions as well as voice-over instructions. This inclusivity in design accommodates varying learning styles and ensures that a broader audience can easily understand work instructions.

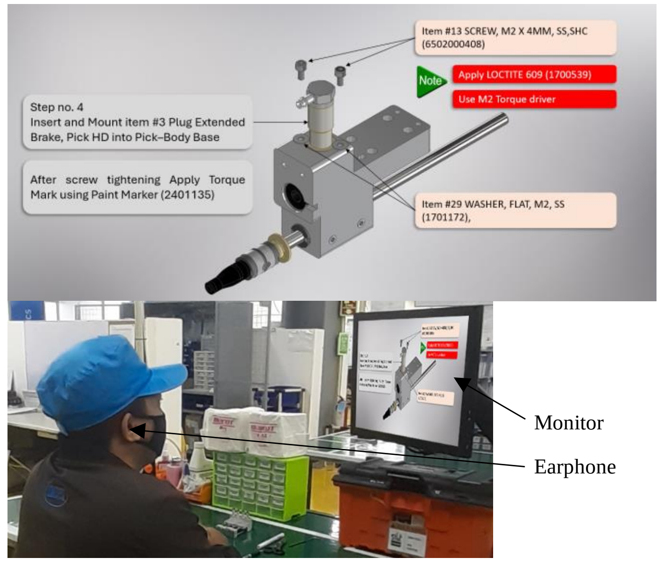

Fig. 5. The animated CAD-rendered Pick body Assembly the AI-generated captions being displayed, and the AI voice-over instruction heard in the workstation during the assembly process.

2. 0 REVIEW OF RELATED WORK

Not Applicable.

3.0 METHODOLOGY

The Animated CAD simulations with AI-generated Captions consist of two main components. The first component is a digital representation of the assembly process, simulated in CAD, with a step-by-step guide provided by an AI-generated caption containing specific instructions. The second component is the necessary electronic equipment, such as a desktop computer with Bluetooth earphones, which is equipped with CAD and office software.

3.1 Animated CAD with AI Captions Generation

To create assistive work instruction, Animated CAD Simulations with AI-generated captions which consist of various information in different models of assemblies including texts, graphics, AI voice-over instruction, and animations have been developed, and a step-by-step flowchart to generate the system is provided.

3.1.1 Drawing of mechanical parts, assembly, materials, and tools.

Use the technical drawing and CAD software to create a 3D drawing of each mechanical part, assembly, material, and tools required. This process will begin with the technical drawing and proceed to the 3D drawing of each part, followed by the assembly drawing as shown in Fig. 6.

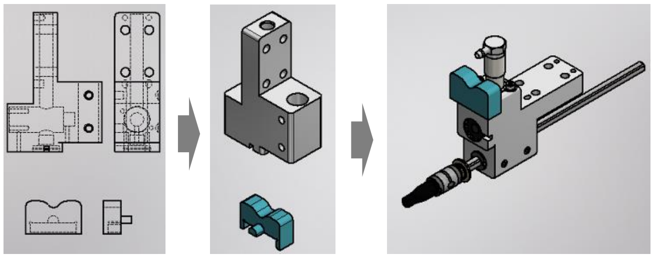

Fig. 6. From left to right are the technical drawing reference, 3D drawing of mechanical parts and tools, and assembly drawing.

3.1.2 Animation of mechanical assembly parts, materials, and tools.

Using CAD software's animation tools, create an animated sequence for assembling parts that are aligned with paper-based instructions, as shown in Fig. 7.

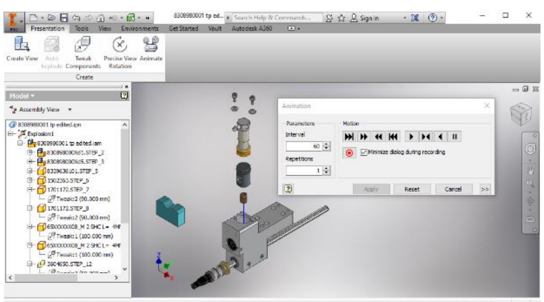

Fig. 7. CAD software animation feature. Pick body assembly being animate.

3.1.3 Generation of captions: text and voice-over

Using the Microsoft PowerPoint application input the text-step process from the given paper-based work instruction including the Part Number and Part Name, Manufacturing Part Number (MPN), material, and tools. Notes, cautions, and warnings should also be mentioned. To embed the AI-generated voice-over use an available application such as TTSMAKER, as shown in Fig. 8.

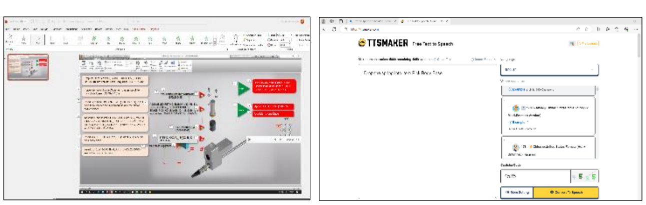

Fig. 8. Microsoft PowerPoint application and the TTSMAKER application.

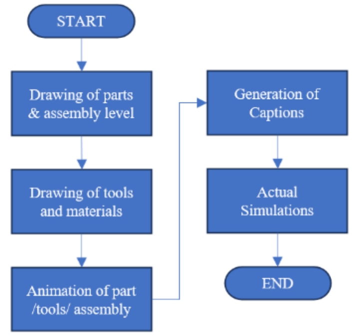

Fig 9. Flow chart of transforming the paper-based work instruction into Animated CAD simulation with AI-generated captions.

3.2 Experiments

In this section, a designed experiment is intended to evaluate the project's performance. The three following subsections detail the setup, evaluation metrics, and subject selection of the experiment.

3.2.1 Experimental setup

To evaluate the performance of the transformed work instructions from paper-based to Animated CAD simulations with AI-generated captions, an experimental setup of one set of Computer on the Workstation is prepared. The full workstation setup for the designed experiment is shown in Figs. 10-11.

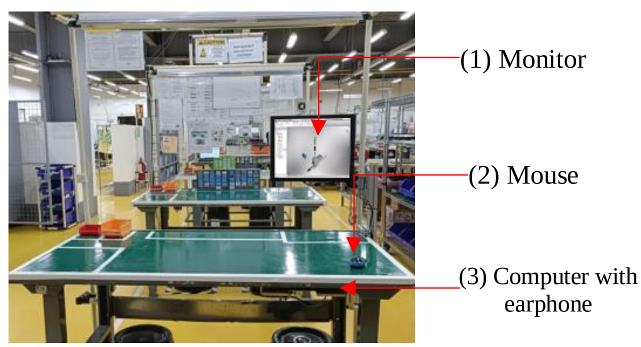

Fig. 10. A workstation setup for the experiment. (1) Monitor- where all animated CAD and Digital documents are displayed (2) Mouse- For Navigation (3) Computer and Bluetooth earphone *(under the table)*- Where the transformed work instruction is stored, documents can be accessed, and AI voice-over instruction heard.

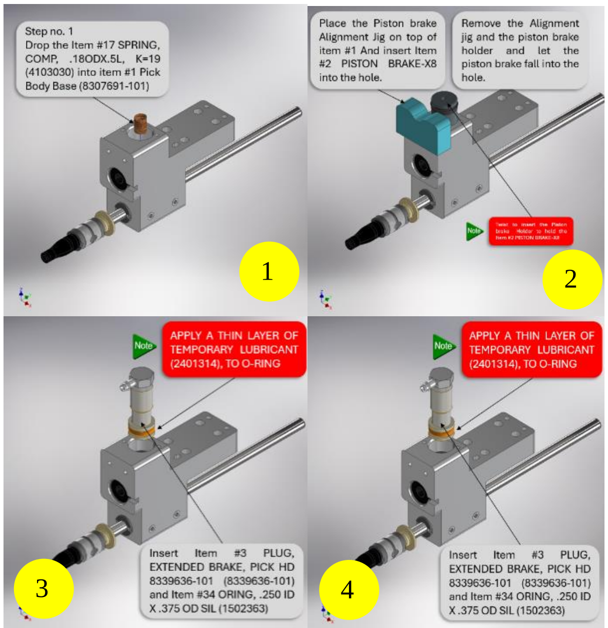

Fig. 11. Animated CAD and AI-Generated Captions of the step-by-step process of pick body assembly, (1) insertion of spring component, (2) Insertion of pre-assemble Piston Brake through Alignment jig, (3) Insertion of Pick-HD Plug Extended Brake, (4) Mounting of Pick-HD by M2 screw and washer.

The experiment is on the Workstation 1 Pick-body sub-assembly process, for which the Assembly Technician would need instructional guidance to finish the sub-assembly correctly. The goal of the sub-assembly task is to insert the pre-assemble piston brake, covered by an extended brake plug with a fitting elbow.

The pick-body assembly contains four steps. Each step consists of multiple operations that require different tools or components. A summary of the information provided by the MPI along with graphical illustrations is given in Table 2. With the defined assembly task, the experimental setup is determined.

The paper-based evaluation was also set up with the use of 1 workstation and the MPI as shown in Fig. 12 and Table 2.

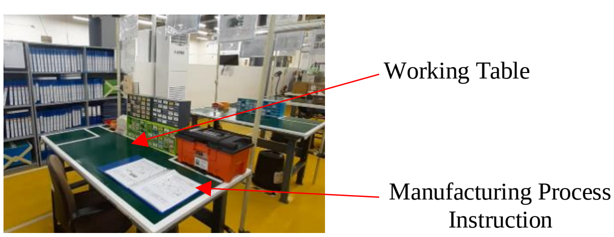

Fig. 12. A workstation setup for the experiment, with the MPI for assembly technician use during the work process.

Table 2. Work Instructions for Pick-body Assembly

Step No.	Step Name	Graphic Instruction	Tool/ Component	Text instruction
1	Installation of Spring		None	Drop the Item #17 SPRING, COMP, .18ODX.5L, K=19 (4103030) into item #1 Pick Body Base (8307691-101)
2	Insertion of piston brake holder		Piston brake jolder	Twist to insert the Piston brake Holder to hold the Item #2 PISTON BRAKE-X8 (8309106-101)
3	Piston brake placement		Alignment jig	Place the Piston brake Alignment Jig on top of item #1 Pick-Body Base (8307691-101). And insert Item #2 PISTON BRAKE-X8 (8309106101) into the hole. Remove the Alignment jig and the piston brake holder and let the piston brake fall into the hol item #1 Pick Body Base (8307691101).
4	Mounting of fitting elbow		M2 Torque driver	Mount the item #3 Plug Extended Brake, Pick HD 8339636101.

Step no. indicates the numbering and the name of each instruction. Graphic instructions show the illustration of each step. Tool/Component are the additional tools needed to perform each step. Text instruction indicates the specific instruction to perform and complete the assembly task.

3.2.2 Subject Selection and Evaluation Method

A Certified Assembly Technician with more than 1 year experience as a mechanical assembler has been selected to perform the experiment. The subject was confirmed to have minimal knowledge of the experiment. First, the subject is asked to perform the assembly by referring to the paper-based manual that is currently available in the manufacturing line. Secondly, he is also asked to perform the assembly using the Animated CAD simulations with AI-generated captions.

3.2.3 Evaluation Metrics

This section describes the metrics used in assessing the performance of the subject assembly technician using paper-based work instruction and animated CAD simulations with AI-generated captions. In terms of productivity, the completion time and number of error occurrences are the most crucial indicators of the performance in an assembly operation. Thus, two kinds of data are recorded when the experiment is being performed. The elapsed time is recorded with a stopwatch, while the number and types of assembly errors are documented whenever a mistake occurs. Three types of assembly errors are listed in Table 3, which are considered the most primitive errors in a manual mechanical assembly process.

Table 3. Three types of assembly errors

Item	Error Type	Description
A	Assembly Order	Assemble with incorrect sequence
B	Tools/Part selection	Misuse the tool/part to conduct the assembly
C	Installation	Assemble with incorrect fixation

The assembly order error is associated with mistakenly assembling a component with incorrect orders. The tool/part selection error occurs when a subject misuses a tool/part. Installation error takes place when a subject installs a part with the wrong fixation, which includes mismatching components and securing them improperly.

4.0 RESULTS AND DISCUSSION

This section discusses the experimental results of the animated CAD simulations with AI-generated captions versus the paper-based work instructions.

4.1 Evaluation result of animated CAD simulations with AI-generated captions versus paper-based work instructions

The results of the evaluation conducted on the Pick-body assembly have demonstrated that implementing Animated CAD simulations with AI-generated captions as work instructions can lead to significant improvements in assembly performance.

4.1.1 Document Cost-saving

This system eliminates the need for paper-based work instructions, resulting in significant cost savings of $9.0, as shown in Fig. 13.

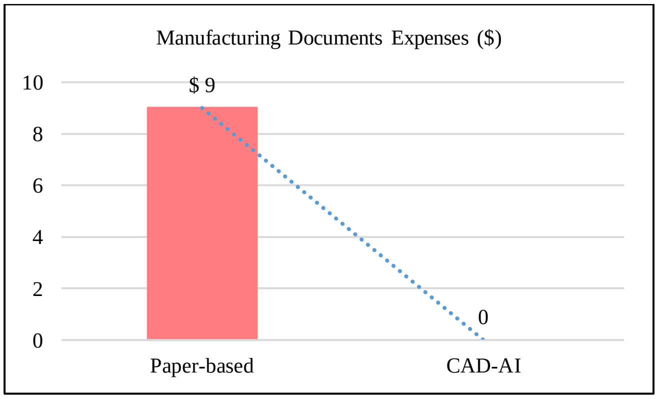

Fig. 13. The cost-saving amount during the evaluation of paper-based and Animated CAD Simulations is $9.

4.1.2 Reduces error occurrence

The system reduces the number of error from 32 down to 12 occurrences or 62.5%, as shown in Fig. 14.

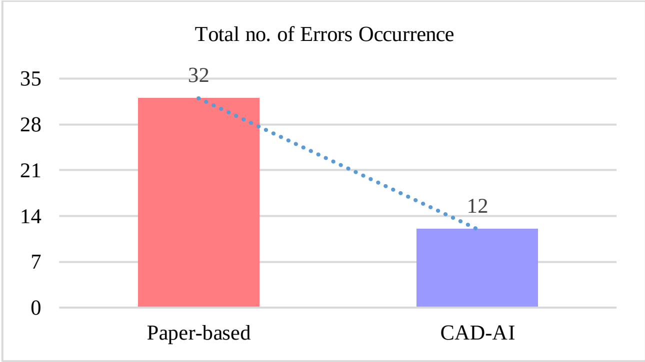

Fig. 14. Total number of errors occurrence using the Paper-based and Animated CAD Simulations.

4.1.3 Reduces Completion Time With Error Occurrence

The system reduces assembly completion time (with error) occurrences from 714 secs down to 303 secs or 62.5% as shown in Fig. 15.

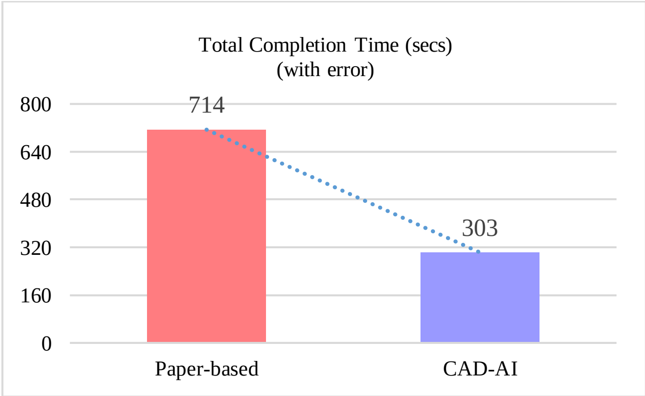

Fig. 15. Total completion time with error using the Paper-based and Animated CAD Simulations work instructions.

4.1.4 Reduces Completion Time Without Error Occurrence

The system reduces assembly completion time (without error occurrences) from 268 secs down to 224 secs or 16.4% as shown in Fig. 16.

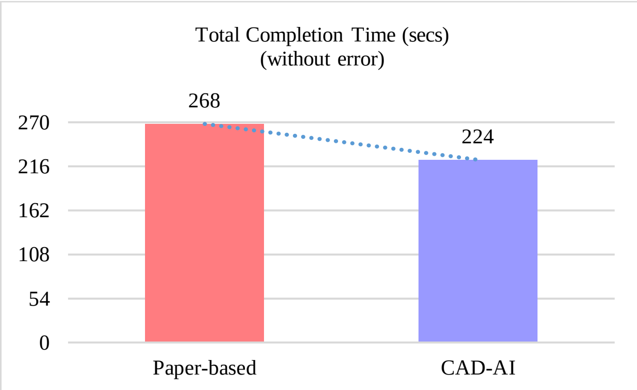

Fig. 16. Total completion time comparison without error of Paper-based and Animated CAD Simulations.

To sum up, the findings from the manual mechanical assembly task experiments indicate that using Animated CAD simulations with AI-generated captions as work instructions can substantially enhance assembly performance when compared to traditional paper manuals.

5.0 CONCLUSION

Utilizing the Animated CAD simulations with AI-generated captions as work instructions in the Pick-body mechanical assembly process can result in significant cost savings. This approach eliminates the need for paper-based manuals, reduces completion time, and minimizes errors, ultimately leading to improved overall assembly performance.

To summarize, transforming paper-based work instructions into Animated CAD simulations with AI-generated captions can greatly benefit the assembly process and significantly enhance its efficiency.

6.0 RECOMMENDATIONS

The application of AI for providing assembly work instructions through embedded assembly videos has proven to be successful. However, it is recommended to make further improvements in the system by incorporating embedded videos that allow users to view different Assembly Isometric Views. This will enable them to verify other crucial details or processes associated with each sub-process assembly.

7.0 ACKNOWLEDGMENT

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