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Digital Mock-up analysis using Artificial Intelligence of Things

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Abstract - Digital Mock-Up units (DMU) are a design or human factor for study and inspection of Computer Aided Designs to help designers identify key design issues and factors which can lead to the functional failure of a product in the early stages of development. Digital Mock-Ups can be used by Computer Aided Design (CAD) & Non- Computer Aided design users to review a product before sending a design to the final stage i.e. Production. Currently, Digital Mock-Ups is used in a wide variety of industries ranging from automobiles to healthcare to aerospace. Additionally, DMU also has some drawbacks such as being time consuming, leading to human errors & repetitive work etc. This paper explores what is the current review process of Digital Mock-Ups in the industry to derive technological & functional information and how latest technologies like Artificial Intelligence (AI) and internet of things (IOT) can be adopted to review Digital Mock-Ups even more effectively using technologies like computer vision and image recognition to reduce human error in the review process**.**

Key Words**:** Digital Mock-up Units, Artificial Intelligence of Things, Sensors, Image Recognition, Object Detection, Machine Vision

1. INTRODUCTION

Since the early ages manufacturing industries around the globe have evolved by undergoing big changes in their manufacturing processes. As industries grew bigger and expanded globally, more capital was spent on producing cutting edge goods which could provide a new and better experience to the customer base as compared to the competitors. In order to produce better experience and new technological experience, manufacturing processes became more sophisticated, which required dedicated set of skills, tools and machinery. Machines and tools were used to make the manufacturing process easier and efficient, which would not only make manufacturing easier, and time-saving and cost-effective. However, the main issue was with the designing of parts. In early days Designing and drawings were done by hand, which was time consuming, needed extreme accuracy and required big amounts of man.

Slowly over time companies started using physical mock-ups as a test medium for their products and developments. A physical mock-up being realistic replica of the product prepared for the validation of design and its fitment testing prior to actual production of the product. Physical mock-ups were quick and easy to create and were also easy to modify structurally. Now a close to reality model was available where the stakeholders and cross functional teams could focus not only on the product structure but also on the aesthetic view in the real world. This provided manufacturing industries with an edge, as by showing the physical structure of the product, industries could get the feedback and views of the stakeholders.

But physical mock-ups had some disadvantages too, while physical mock-ups required additional time, capital and storage space and over a time product structures became more complicated due to which, building Physical Mock-ups became more challenging and becoming a major setback to companies. And even if some project team was able to afford the time and cost to build the mock-ups, it lacked to show the functionality, at which point it was getting difficult to understand the true purpose of the product.

At this period the need for digital mock-up units (DMU) arose in the market, which represents more likeness to the actual model on a computer system. DMU is a computer created and simulated model of a product, where the functional aspects of the system and its subsystems can be tested and validated. Dimensional analysis can be done which can show any missing or incorrect dimensions, structural analysis can also be performed which highlights the structural improperness or fouling of connecting objects, which can save industries, both time and capital also eliminate the need of physical models, as DMU is not just a process which ends after a product or structure is built or finalized but it is the entire process of engineering across different disciplines and a variety of working principles being put into play.

DMU had several advantages over physical mock-ups, including the fact that they not only saved the cost of having to build a physical model, but also saved time and resources. Additionally, DMUs identifies errors in design, structural faults, or functionality issues, which can be a major challenge for industries to solve at later stage if they're to overlook them. DMU can also be offered to stakeholders and investors Worldwide without the need to call them physically. DMUs were rapidly adopted by industries and are still in use today, thanks to the numerous benefits that provided by DMU.

Currently DMU analysts review mock-up files manually to locate errors and faults in structure or do dimensional analysis for any kinds of design issues. While this process maybe the current practice in industries, it is time consuming and also sometimes leads to human errors which are reviewed and corrected at later stages. To avoid such kinds of errors, many functional aspects of DMU can be automated using Artificial Intelligence (AI), which can not only bring the chances of human errors close to zero but also give new feedback and suggestions to users on how existing products can be modified or in which subsystem changes can be made to gain an edge in the market. In other words, AI can be considered as the brain of the smart system. Even after using AI for DMU review there will still be a need for human intervention as AI is not being used to automate the entire lifecycle process but to help reviewers, get a more transparent outlook of the product and take action based on the final review.

In the upcoming chapters we shall talk about the DMU's current review processes, error-prone areas and how artificial intelligence (AI) can be utilized to identify errors and other faults, we will also analyze at what point human intervention is required beside AI review, later we will study what design flaws the AI must find, and how this information will be conveyed to the user, stakeholders, investors (including non-CAD users), and other parties.

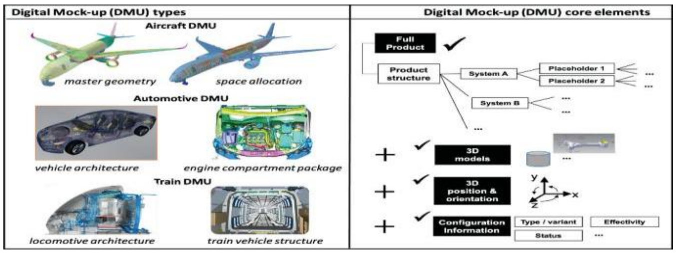

Fig 1: Types of Digital Mock-up

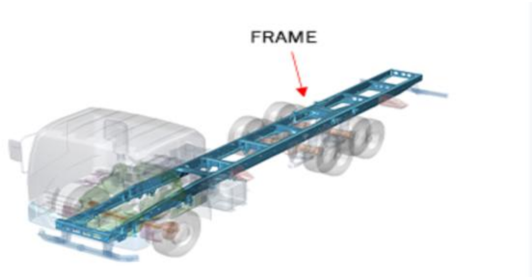

Fig 2: Work being done on DMU of a Frame Assembly

1.1. Concept of AIOT

AI & IOT are two different segments which come together to form AIOT. Artificial intelligence (AI) is an intelligence system created by human users for computer systems or electronic devices which simulated the way a human would think and perform tasks. The goal of AI is to make predictions about future conditions or assumptions based on large amount of data generated which is fed to the AI model to train it. When an AI model is fed data, the focus remains on helping the AI model to identify a pattern in this data, based on this pattern AI will work to find matches in inputs given by humans which will help it in giving a proper solution. The four main pillars on which an AI model is based are learning, reasoning, self-correction and creativity. To summarize AI is a machines intelligent ability to perform cognitive functions like a human mind, such as performing calculations and providing solutions to problems, logical reasoning and showing creativity.

IOT on the hand is very different from AI. It is a collection of physical objects, which are connected to, sensors of different kinds, visual monitors like cameras and lenses which are constantly collecting data from the environment around them and sharing it over the internet, with the goal of connecting and sharing data across devices that can be present in any location around the world. Data from these connected devices is stored in the cloud, which can then be accessed by any of the devices on demand basis or an AI model.

1.2. Importance of AIOT

A. **Efficient work management:-** By using AIOT small medium and large-scale businesses can optimize their business process, improve process management, and monitor performance delays and get suggestions for improvements. By using IOT sensors and devices can collect data about their operations, maintenance costs and downtimes which can be stored in cloud servers across the world and can be accessed from any location.

B. **Decision driven decision making:-** AIOT connected devices gather vast amounts of data from sensors to give suggestions and feedback to the end user. Using AI models to analyse and study the data collected by IOT devices & sensors can help the business gain insights on operations standards, process downtimes, customer behaviour patterns, market trends and business performance enabling make more efficient workflows using AIOT technology and gain market insights as compared to competitors.

C. **Cost Savings: -** The major impact of AIOT is in cost savings. By using technologies like deep learning and neural networks in DMU model review. AIOT businesses can automate repetitive tasks and reduce unnecessary manual process which will not only help a business cut down on costs, by allowing the business to monitor energy consumption, thus reducing unnecessary energy costs, and enabling the business to be more sustainable economically and socially.

D. **Satisfying Customer Expectations: -** By gathering and analysing market data using AIOT devices, businesses can provide a more personalised experience to customers, which creates a lasting brand impression in the minds of the customers. This data will be huge hence storage can be an issue for most companies, but by using cloud storage spaces, companies can not only use this to store customer/market data but also use this data to train the AI model.

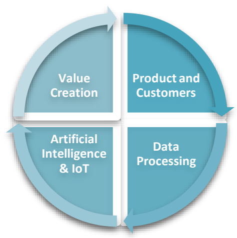

Fig 3 - The benefits of AIOT.

1.3. Application of AIOT in different phases of Product

In this Section, we will see how the integration of Artificial Intelligence and Internet of Things (AIOT) technology helps designers, manufacturing engineers, sales teams, service teams, and other stakeholders throughout various stages or lifecycles of product development. Generally, all products have their own lifecycles or phases which they must go through. The first stage of the product lifecycle is conceptualization in which ideas are developed and the best one is finally chosen. The second stage involves the actual design and development of the product, which is based on the final concept. After design completion the manufacturing phase started, and it starts when the plant actually starts to manufacture products. The Sales Phase is started when the product is ready to sell to the customer. The service phase, which begins after the product is sold and when company started providing services for the product. The final Stage is the recycle phase which starts when the product is recycled after its working life is over and product becomes unusable.

A. **Conceptualization phase:** Artificial Intelligence and Internet of things plays an important role in CAD design and automation. This combined technology improves the designing process with minimizing design errors and reducing the manual intervention in Concept design and finalization. AIOT enabled devices and sensors can collect large amount of information from the predefined set of environments and can be used for generating multiple concepts. AI will then help to choose or finalize the best concept among other based on the analysis of the data. With the implementation of AIOT in this stage stakeholders can not only review the design ideas, but also get new suggestion from the AI model. It can also suggest improvements to the idea or modify the idea as per the stakeholders' requirements. Sensors and visual devices embedded in the IOT system can provide data, which is already available in the market or, is like the concept being developed, this data can be then analysed by the AI model which could give improvements or suggestion, for the current concept.

B. **Design and Development:** Based on the conceptualization phase a functional design is created of the product to be developed. The design stage involves a lot of manual research work and flaw detection which can, not only be automated with AIOT but also researchers can get creative and innovative improvement suggestions from the AI model based on their requirements. AIOT automation of the design can include quick detection of design flaws, design improvements or modifications wherever necessary. Using AIOT can help designers and stakeholders understand how a product design can be further improved to meet the market needs without going through the manual process of design flaw detection, especially for small areas which might not be possible to show on a physical model.

C. **Manufacturing:** The modern age industries follow Industry 4.0, which brings with it automation, interconnected devices and data exchange between machines and tools. The future of such industries is AIOT, which can not only bring intelligent automation of tasks, but also increase productivity, and bring about better-quality control. With IOT sensors built into the machines and the availability of cloud storage technology, gives AI the advantage, of referencing data wirelessly from any part of the industry. With this referenced data the AI model can then guide the machines or machine arms to function in a more efficient way which will need minimum human intervention, reduce repetitive tasks and detect production defects among parts. This not only gives the industry a market advantage but also opens new opportunities for the industry to explore areas by which it can improve the already existing process or bring about new development.

D. **Sales and after sales services:** Artificial Intelligence and Internet of things plays an important role in the sale of a product. Companies can use AIOT to give customers a view of the similar model of the product which they want to purchase. For example, if a customer is looking to buy a car, then he/she can visit the company's website where a base model of the car will already be present and customer will have options to customize each exterior component of the car, like car colour, wheel rims, and window glass colours. This is possible due to IOT devices which are there at a particular location, which is uploading data about the cars offered by the company to the customer directly on their devices. Once customer is done with making their choices the AI model can suggest changes in the choices of the customer which can make the functionality of the car more efficient and comfortable for the customer.

Fig 4: AIOT application at different phases of product lifecycle

2. Integration of DMU & AIOT

Digital mock-up unit or (DMU) is virtual representation of a physical model where each and every subsystem can be viewed and inspected by stakeholders for the cause of modifications or improvements in the overall performance of the product being designed. With the integration of AIOT in DMU, stakeholders can get inputs on how efficient the design is, what process can be followed for manufacturing and what are the materials that will be needed for the manufacturing process. With the integration of IOT sensors in the shop floors, production lines, and manufacturing stations, data can be collected on how the process of manufacturing is being done, what are the materials being used.

Other than these, sensors and data capturing devices can also be fitted on vehicles, both test vehicles and vehicles supplied to customers. These sensors will capture data from the vehicle in, on-road conditions. Data like material strength, under, loaded and unloaded conditions and in different temperature conditions, performance under different road conditions, vibrations of the material at different speeds of the vehicle. All these data's can be collected by the IOT devices and stored in cloud. An AI model which is configured with the IOT devices and the cloud storage system, will analyse the data, based on this analysis the AI model will provide feedback and suggestions to users and stakeholders who are working on a model of the same or similar kind of product from which data was collected, as the AI model will be integrated with the CAD software's which are used by the users or the companies. This will not only help the users review the cad model of the product but will also help them identify flaws and areas of improvement based on the data which was collected by the AI model after analysing the data from the cloud storage which was collected by the IOT sensors.

For example, someone working on chassis of vehicle in CAD will get useful, and intelligent feedback based on real world data. The AI model integrated in the cad software will review the cad model of the vehicle chassis and based on its review it can guide the user to make modifications or improvements. The AI model can also detect faults and errors like fouling parts or Improperly designed parts in the model which are not according to the standards, and which can result in more rework. This results in less repetitive tasks for the user and improves process efficiency, also the AI model will give feedback on whether all parts are at the proper place or if there are any parts having wrong material assigned to them, or if there is any substitute part available, which can perform the same job with lower cost and with much lighter weight. This will prove a benefit for the users as they can test out the suggestions given by the AI which can improve the overall manufacturing process and also help detect hidden flaws.

2.1. DMU review process presently:

Large Cad assembly models consist of multiple subcomponents essential which are need for the overall product to function and define the purpose of the entire model. These datasets allow companies to present their products or services, which can also serve as references for others to develop new products. DMU review plays a critical role in this context by providing clear insights of product in every stages of design & manufacturing. They rely on assembly models, reviewing the entire model and inspecting all components for modifications or design changes. DMU reviews include geometry checks, component layouts, fouling checks, dimension verification, and structural behaviour analysis to ensure customer and stakeholder requirements are met. These checks are often performed at a subassembly level, sometimes which also include simulations to test real-life conditions. The process begins with an analysis where stakeholders examine the model's consistency and technological integration, addressing issues like geometric errors, structural flaws, or incorrect materials. This stage includes suggestions for improvement. Next, the data is assessed for reusability in similar tasks, which is often viewed in light modes to ensure compatibility across various software, reducing the cost of format conversions for different CAD softwares. Mark-ups, annotations, dimensions, and comments are then verified for clarity and alignment with business requirements. Comparisons are made between 3D objects and stated specifications to identify discrepancies. Currently, these steps are manual, requiring significant time, effort, and resources. Multiple team reviews often lead to varying perspectives, causing delays as modifications and rechecks are necessary before final approval. This can likely increase the risk of error leading to costly and time-consuming rework, also manual review of large-scale cad models are difficult and time consuming, in the upcoming chapters we will see how these challenges can be minimized using AIOT.

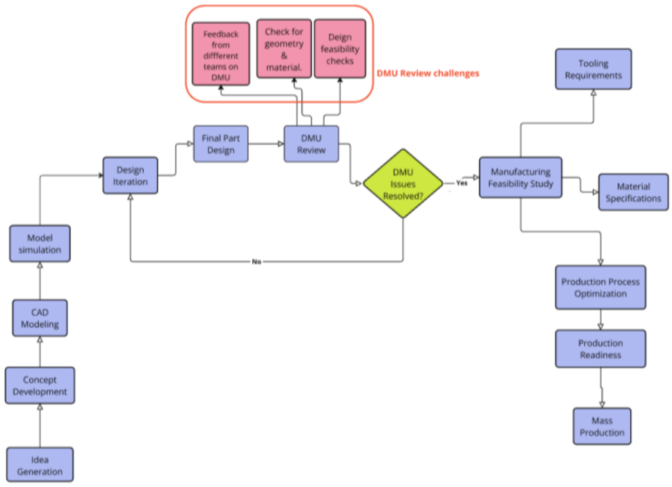

Fig 5 – Current DMU review process with Challenges

2.2. Layers of AIOT system

A. **Cloud database: -** For the AIOT model to work successfully a database has to be created from where the AI model will refer images captured by the IOT devices. The database should be created on a cloud base, so that it can be accessible from any location in the world. Captures taken by the IOT devices installed in various places will be uploaded in this database for monitoring and reference by the AI model. This cloud-based database usually consists of three to 4 layers which communicate with each other to process data transfer across all connected devices, including the user and back. [20]

B. **Perception layer: -** The perception layer is the base of an IOT system. It includes both sensors and actuators that acquire and process data from externally connected devices across locations. This layer plays a crucial part in gathering raw data from physical environments in real life conditions. The data acquired from this layer is sent to higher levels within the architecture for storage and analysis by the AI model. Without the presence of this layer, systems would lack the ability to collect key information required for the AI model to do its task and provide feedback to the user. [20]

C. **Network layer:-** The network layer, which also known as the transport layer is an important part of the IOT network as, this layer oversees the communication of digital data between all elements and layers of the IOT architecture. This layer uses technologies such as HTTP (Hypertext Transfer Protocol), MQTT (Message Queuing Telemetry Transport) and AMQP (Advanced Message Queuing Protocol) to facilitate the transfer of data from one application device to another. Asymmetric keys are used to secure data transfer, which uses two different keys for encryption and decryption which helps to keep the data transfer safe and free from cyber-attacks. [20]

D. **Data Processing/Cloud Layer: -** This is the layer where data processing occurs, using cloud computing resources, to store, analyse and visualise data. This layer hosts components like AI engines, data storage systems and certain analytics tools. The AI engine architecture is based on data flow technology, which means that that the AI engine will process each image multiple times based on certain rules and principles before labelling it with an identification. This AI engine is like a grid, which is made up small processing units also known as tiles, which are a range from 10 to 100 tiles in one grid. These tiles work together with each other to process any kind data or pictorial information and read it as a whole image. [21]

E. **Application layer: -** In IOT architecture, the application layer protocol is a crucial part of the IOT architecture. It serves the purpose of bridging the line between the IOT devices and the users. The application layer is often tailored to serve specific use cases, such as image monitoring, feature recognition, and image segmentation by the AI engine. With the help of an AI in the application layer data analysis and pattern recognition will become more efficient and optimised. The application layer uses protocols like MQTT (**Message Queuing Telemetry Transport**), COAP (**Constrained Application Protocol**) & REST (**Representational State Transfer**). Protocols like MQTT, COAP & REST are mostly used for real time low latency data transfer between IOT devices and user interface enabling smooth and optimised data flow over varied bandwidths. The AI models will be implemented directly on the data stream in this layer, which will help in aggregating the data from multiple sensors and devices as per the requirements, while also compressing images and other data bytes to optimise server performance.

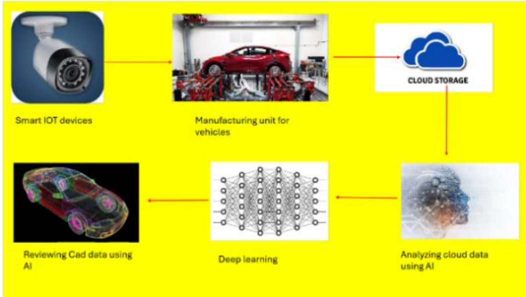

Fig 6: - Deep learning model of AIOT in Image recognition

3. AI & IOT frame for DMU

3.1. Data collection and preprocessing: - Sensor data must be cleaned and preprocessed before training AI models to avoid inaccuracies. Techniques like data labeling, segmentation, noise removal, outlier detection, and handling missing data are essential steps. Incomplete or duplicate datasets require cleaning or modification, either manually or using AI tools. Images for AI training are represented as pixel matrices in binary form. Any image having blurriness or patches can be corrected by adjusting the image kernels, often using a Gaussian probability model which is statistical probability model, which is used to determine the probability that each data point or kernel belongs to a given cluster. This statistical method determines the most probability of data points belonging to clusters and can be applied to vehicle data collected by the IOT devices for preprocessing before feeding the data to the AI server

3.2. Data Augmentation: - Data augmentation is a process of creation variations of an existing dataset to better improve the training process of AI models. The main purpose of data augmentation is the fill in the gaps within missing or incomplete datasets to complete the dataset and set it up for analysis and training and thus improving and optimising the machine learning process, which improves model generalization in image recognition & classification by expanding and diversifying the training dataset through multiple image transformations. Augmentation can be an extremely valuable training technique as it exposes the model to a variety of different datasets in different perspectives, lighting conditions, orientations and potential distortions, all these will enable the model to make better decisions and provide better analysis for any data which may be provided. **[25]** Data augmentation involves various techniques like, image rotations, scaling, and flipping, translation, and color contrast and brightness adjustments.

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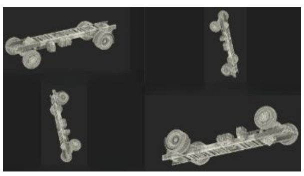
Fig 7: - Data augmentation [25]

3.3. Rotations - In this step images are rotated between 0 degrees to 180 degrees to create alternate copies of the original image with different perspectives, giving different views of the same image from different angles. This trains the model to understand different perspectives of the image pixels/kernels and will also help the model to recreate an image from partial or missing data based on the available kernels on the server. Mathematically rotation is applied to each pixel of an image and the total group of kernels is viewed as a matrix, hence when rotation is applied the entire matrix is rotated and the pixels are rearranged.

Mathematically $R = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix}$

Where θ *is* the angle of rotation for each kernel of an image, hence a positive angle rotates counter clockwise and a negative angle will rotate clockwise.

3.4. Scaling – Scaling such as zooming in/out or cropping image is done to create new samples from existing data, this method of augmentation, helps in training the AI model to better identify images even if they are blurred out or half cut. Real world objects can be of different size and shape, & scaling an image provides wider data diversity and exposing the image to a scaled version which can be easily identifiable, along with that, IOT devices can take images from any distance which can be difficult to be identify by the AI model, hence cropping or rescaling the image will give a better perspective which will be clearly identifiable and can also be used in the AI's training.



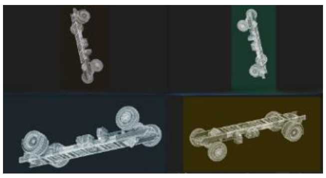


Fig 8 : - Data augmentation (Rotation)
Fig 9 (Right) : - Data augmentation (colour filtering)

3.5. Colour filtering (changing brightness, contrast) – Photometric transformations such as enhancements of colour, brightness or contrast are done to mimic real world conditions, in the real world photos can be taken under different conditions where the lighting can vary and the environment can be different based on each scenario, hence to mimic these conditions and help the AI model better recognize images colour filtration is done which can mimic different lighting conditions from different kinds of environments. Brightness, contrast and colour are randomly applied to each pixel of an image, which causes the required changes to take place. For change in brightness each pixel of an image with R,G,B (Red, Green & Blue) values, are changed. As the maximum pixel values for 8-bit images are 255, hence a random range is chosen usually between **($0.5 \leq b \leq 2$)** which varies the brightness (**b**) within this range. Similarly for adjusting contrast typically a value of **127.5** is set to each pixel for an 8-bit RGB image. If (contrast) **$c > 1$ then** contrast increases making the lighter areas dark and the darker areas more dark and if $0 < c < 1$ then contrast will decrease making the image appear more flatter. The contrast level is usually kept between **$0.5 \leq c \leq 1.5$** to get a varied output.

Fig10: - Contrast filter applied to an image (Left, without contrast & right image with applied contrast)

3.6. Gaussian noise – Noise in machine learning refers to any kind of variation or distortions in the datasets that can make underlying patterns of data difficult to be identify. Noise can also be any form of unwanted element or variable which can otherwise make an image difficult to read for the model and hence interpret incorrect data. Among this Gaussian noise is a type of noise which is follows a normal distribution with a mean (μ) of 0 and a standard deviation (σ) of 1. It is usually visualised as a bell curve shaped distribution. The normal distribution also known as Gaussian distribution is a type of continuous probability distribution that is defined by is probability density function (PDF). [26]

Hence mathematically
PDF(X) = (1 / (σ * SQRT(2 * π))) * E^(- (X — μ)² / (2 * σ ²)) [26]
In the above equation

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X = random variable, μ = mean and σ = Standard deviation

Gaussian noise is introduced in training data to train model on real life condition. This exposure to gaussian noise makes AI models more robust and exposes them to a variety of data possibilities. Also, models trained on gaussian noise have better image recognition capabilities and the introduction of random disturbances encourages the model to recognize broader patterns. For most models sets that are trained a mean value of 0 is used which results in a noise that does not shift the overall brightness value or signal distribution form the image, hence allowing the image to keep its original characteristics.

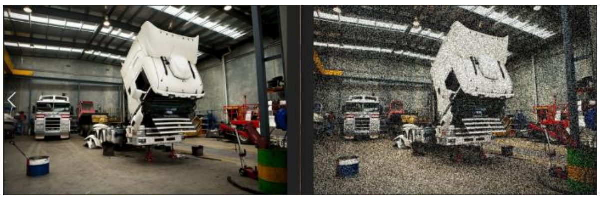


Fig 12: - Gaussian noise applied to two different images. Left image is noise free and right image has noise added to it with an intensity of 90%.

3.7. Object detection – Object detection is a computer vision specific task which involves detecting the location of an object in an image or video with a specific label or dimension. Autonomous driving vehicles use this feature to detect pedestrians and vehicle on the road and then label them as per their category. This feature is also used in manufacturing industries to identify defective products which do not meet the manufacturing standards and label them for further processing.

Firstly, the image passes through a convolutional neural network (CNN) to extract features like image position, colour, shape and edges. Mathematically

$$F(i,j) = \sum_m \sum_n I(i+m,j+n)K(m,n)$$

Where

- $F(i,j)$ = Feature map at position (i, j)
- $I(i + m, j + n)$ represent the Input pixel values
- $K(m, n)$ represent the Convolution kernel or filter

After the features of the image/s are detected a bounding box regression function takes place where, the detected images are boxed based on the coordinates of the images position based on (x,y,w,h), these dimensions are usually predicted by the model before boxes are created.

Where

- x, y = Center of the box
- W, h Width and height of the box

Fig 13: - Tests performed for object detection in an Environment with humans and vehicles

3.8. Image classification – Image classification is the process of finding out which category an image belongs to from already predefined categories. An approach called "bag of features" (BOF) is used to identify and classify images according to their categories. The idea behind BOF is to extract local features from an image using algorithms like SIFT (Scale-Invariant Feature Transform) or SURF (Speeded-Up Robust Features) and then use clustering technique to group the features into a set of virtual words, each image is then represented by a histogram which is called a bag of features. [27]. These features can be extracted from any part of the image and in random orders, after which grouping or clustering the collected features of the image into a set of visual words, usually done by applying techniques such as K-mean or hierarchical clustering for the descriptor vectors. Then each cluster represents a visual word. For the final step the image is represented by a histogram of the visual words, this is usually done by counting the number of features that belongs to each visual word and creating a histogram based on these counts. .

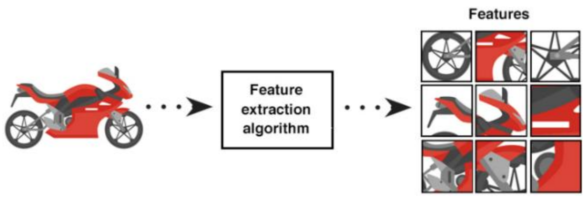
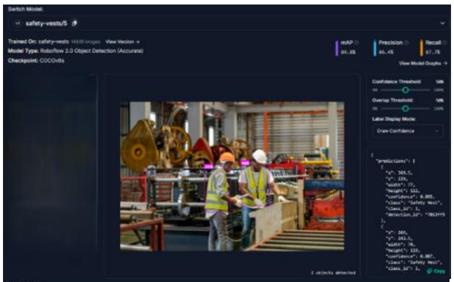


Fig14: - feature extraction in image classification [27]



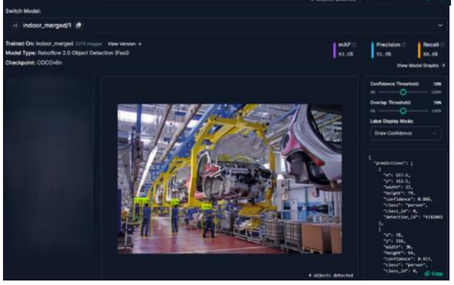
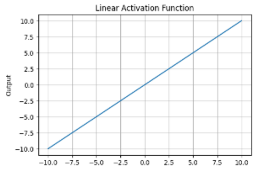


Fig 15: - We tested a sample image for object detection on a model which has been trained to detect safety vests. Model used: - YoloV8

Fig 16 (Bottom) - We tested a sample image for object detection on a model which has been trained to detect people in indoor conditions. Model used: - YoloV8

4. Application of Deep learning in DMU review

4.1. Deep Learning in DMU image recognition – Deep learning uses convolutional networks to analyse, learn, and memorize data, mimicking the human brain. It generates algorithms that learn rules from sample data to extract features like characters, colours, and shapes. In the context of DMU reviews, deep learning classifies vehicle images as RGB, performs data augmentation, and creates a matrix with coordinates for convolutional layers. These layers extract spatial features by down-sampling images or reducing dimensions. Activation functions within deep learning networks introduce non-linearity, enabling the network to learn complex patterns. ReLU (Rectified Linear Unit) outputs the input if positive or zero if negative, acting as a selective filter because of the zeroing operation that generates data variants and improves backpropagation efficiency. SoftMax, activation function, which is suited for multi-class classification, converts input vectors into probabilities, helping the AI model identify specific features like edges or shapes. It assigns a confidence score, allowing the model to select the class label with the highest probability. For DMU review the SoftMax function can be more beneficial as it is not limited only to binary classification and works on multi class labels, by taking an input vector kernel from a neural network and generalize them into an array of probable augmentations, which helps determine specific features or edges or characteristics of an image. **(32) (33) (34)** Hence the SoftMax function can more efficiently capture features from vehicle images and pass these extracted features through the confidence score filters in the CNN networks. These images will be thoroughly analysed based on features like edges, dimensions, colour, and contrast and pixel data. Based on these features the images which gets the highest probability score will be picked and analysed by the AI model and based on the features from the images picket the AI model will match the feature data with the vehicle parts in DMU and give its feedback to the user.



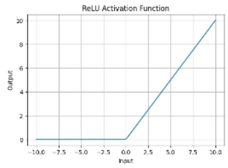


Fig17: - linear activation function. (It returns the input as the output) (32)
Fig18: - ReLU activation function. (32)

4.2. Convolutional neural networks (CNN) in DMU review - For our case of DMU review each image which is captured by the IOT device will be passed through convolutional layers, to process the image features and extract those features such as colours, edges, grid topology, dimensions. The convolutional layer is the core building block of neural networks from which the AI model will take the best possible output to analyse before checking on the DMU model. The CNN usually works with three dimensions, in connection to RGB in an image. Also, there is feature detector present in CNN, which is a 2-D array of weights representing the image. While there are multiple layers in a CNN network containing different kind of filters in each layer. While some filters may extract colours, others may detect edges, and even others may detect shapes, the filter size is usually a 3x3 matrix, the matrix size also determines size and capacity of the receptive field. The filters are then applied to an area chosen randomly in the image, a mark is produced which is then calculated by comparing it with the input image pixels and the features extracted by the filters. This mark is then transferred to an output array, where the image is partly reconstructed, after this the entire process

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repeats in which the filter is then applied to another area of the image. The CNN model will be trained on different vehicle aggregate images from different scenes which will give the CNN network a wide variation of samples of 2D images from different perspectives allowing layer by layer analysis for both small & large datasets. Pooling layers present in the CNN network are used to down sampling the feature maps extracted from the input image while retaining important features. This creates a summary of extracted features covering all parameters while also reducing data size, reducing model complexity and improving computational power. From here the down-sampled features are sent to the fully connected layers where a linearity is established between the features and the input image based on predictive weights and biases, after which the number of neurons in the final fully connected layer (FC), matches the number of output classes among the classified features. The input image or images are then reconstructed here while applying batch normalization to the activation functions which prevents internal covariate shifts from the input image. After the images are reconstructed with the extracted feature, one image from each classification group will be picked by the AI model based on probability score. This image will then be further analysed by the AI model based on pattern recognition. This data is then stored in the neural networks of the AI, which will be recalled again when viewing DMU data. The patterns learned from the image will be compared with the vehicle DMU based on parameters like geometry, colours, shape, edges and dimensions. After comparing these features if a mismatch is found, the AI will give appropriate suggestions to the end user and if there are no mismatches then no error will be mentioned and the DMU is ready to be sent forward.

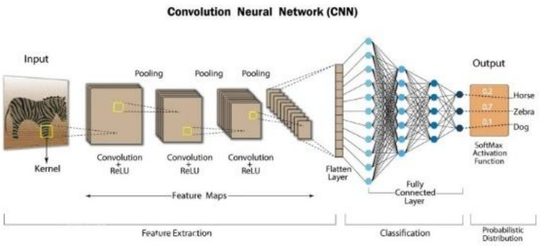

Fig19: Basic structure of CNN

5. **Pixel level understanding of DMU in deep learning -** When a vehicle or part image is capture by the IOT device, that image is in its raw form and needs rectification to train and be understood by the AI so that it can better recognize the DMU data just by referring the input image from IOT devices. While feature extraction is an excellent way of training the neural network, but when combined with semantic segmentation makes the training even more impacting. Semantic segmentation works at pixel levels, where it will assign class labels to each pixel of the image captured and label those pixels such as category, shape and size, this is a very important training needed for object recognition in real time. From the entire vehicle DMU if only a specific part of a specific aggregate were to be identified, then for that grid mapping is performed of the entire image give the network an idea of the position of each object and the total count of objects presents, next a, encircling boundary is generated just around the object to highlight that object. Taking reference from this data received from the fully connected layer the AI will use this data to recognize objects in DMU by mapping the grid of the entire DMU giving it an idea of how many objects are present and then recognizing using BOF (bag of features) technique, to retrieve features and semantic labels. This allows the AI to detect, recognize and label objects from the DMU in real time, while also giving feedback to the end user.

6. **Automating DMU review using AIOT models: -** DMU review in industries currently is a manual, repetitive task which is not error free. DMU review takes place among various teams where different teams might have different opinions about the product or functionality, which increases the chances of delay and rework, costing more time, effort and capital. To minimise these errors and increase efficiency in the review process, the AIOT model can be used to review DMU structures, saving time and manual repetitive work. The AIOT model can be installed in any manufacturing shop floor, where the IOT devices will take snaps of vehicles or aggregates and send them to the cloud for storage. Deep learning using neural networks & activation functions is performed on these images, in a CNN network layer from where random features are extracted from the image and the image is reconstructed again using these features. Then the reconstructed images are chosen by the AI for further analysis using pattern recognition technique which enables the AI to identify and recognise and part or structure of a vehicle in DMU. This is a continuous process where the AI keep on learning and recognizing new patterns to identify objects better. This entire cycle is automated where the IOT capture images and the AI learns the patterns

to recognise those images and then identifies objects in DMU.

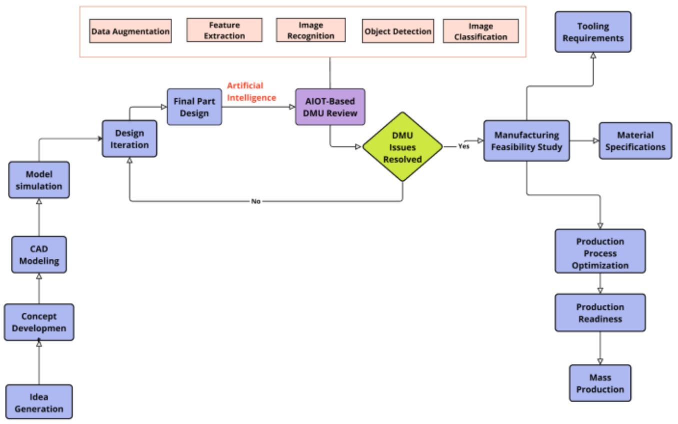

Fig 20: AIOT implementation in DMU review process

Conclusion - Using the AIOT technology will not only make the DMU review process more efficient, but also reduce manual work, saving cost and resources of the company and making time for work which needs more attention. By leveraging the power of AI and the connectivity of IOT devices, companies can reduce manual work, achieve greater efficiency, and receive real time feedback on their DMU models, thus reducing errors in the review process by a large extent. AI-driven image recognition enables the automated identification of design inconsistencies, while IoT integration ensures seamless data collection and analysis across all stages of development. This collaboration between AI and IOT enhances and accelerates decision-making process and but also enhances collaboration among different teams by providing actionable feedback on DMU of products. AIOT integration for DMU reviews establishes a robust framework for continuous improvement, innovation and maintaining high product standards in the design and manufacturing industry.

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