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Reverse Engineering in DTs Using Object Detection

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Abstract

Object detection has become a fairly widespread method in recent years for computer processing that uses artificial intelligence to detect certain sought-after objects in digital images or videos. Object detection and recognition techniques have also experienced continuous development as their implementation, use, and benefits have become extremely evident through the speed with which answers are found in the images submitted to attention. Thus, applications that use object recognition have become very diverse: recognition of people, autonomous cars, construction of robots, voice recognition, automatic translation of texts and spoken messages, robotic surgery and patient-centered medical care, recognition of components in industry, recognition of manufacturing defects, recognition of crops, etc.

This paper is a further step of previous research that proposed innovative methods for object recognition using advanced CAD tools (CAX), when the custom data-base does not contain images of objects, but CAD models of them. This step studies the use of object recognition in Reverse Engineering methods, i.e., updating a CAD model based on object detection.

Keywords: Object Detection; DTs; AI; CAX

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Introduction

Object detection (OD) has so many applications in so many research directions that has become a new science today.

But object detection techniques have been developed, focusing on several aspects specific to the required purposes:

- Segmentation of images as clear and correct is possible;
- Object detection and classification;
- Evaluating the position and orientation of objects;
- Evaluating the size of objects and measuring distances;
- Some particular properties of objects – color, growth stage, degradation stage, health monitoring by detecting and evaluating spots on human skin, etc.;
- Studying multiple parameters through successive images (motion tracking in digitally recorded videos).

All these aspects are evaluated based on criteria for precisions in detection.

Almost all of these applications use special techniques based on information from pre-saved datasets containing images of the object of study, from various positions of it, at various stages of development (in the case of fruits, vegetables, and systems that are assembled on production lines), with various specific lighting or coloring modes, etc.

Every object detection technique also has disadvantages related to the accuracy of detection, due to the conditions and quality of the captured image. Real capture conditions are often far from being acceptable compared to the situation when the object is photographed in an ideal laboratory scene.

Almost all researchers in the field of object detection have focused on improving object detection software, using new and more advanced computational methods in im-age processing. However, in this case, the methods have some limitations. Other re-searchers have focused on the speed of image processing methods, trying to work with a much larger database. But here too, the methods have some limitations in detection accuracy.

Many of these techniques were developed to solve tasks similar to the way human intelligence operates, such as how to interpret images and what we see, how we learn, some aspects of reasoning, decision-making, estimating of the best next steps, estab-lishing clear criteria for evaluation of accuracy in estimations, etc. Therefore, many of these applications are now called artificial intelligence technologies (AI). The use of AI is now proving to be of real help in faster selection, evaluation, and optimization of data types through neural network methods specific to these artificial intelligence methods [1].

Computer science has developed much further than that. Starting as a necessity for engineers to perform faster mathematical calculations, it has continued to develop to use computers for scientific and personal use to exchange, store, and access information worldwide, becoming a tool for everyone and for every need.

A particular direction in the development of computer science has been the reconstruction of real objects in a virtual form so that complex objects can be more easily observed, studied, and analyzed even under aspects of multi-mechano-physics-chemical interactions. These methods of representing objects virtually and the related model are called CAD (Computer Aided Design) models.

The emergence of CAD applications led to increased productivity of engineers and researchers for industrial development and advanced academic studies. The accumula-tion of information from experimental measurements came to complete the initial doc-umentation of a project through CAMM (Computer Aided Measurements) methods and this information was even incorporated into professional CAD applications.

CAD applications have gained increased power in evaluating the structures and phenomena to which components defined internally by the geometry of the parts are subjected. Thus, CAE (Computer Aided Engineering) applications emerged.

In recent years, the technology of creating parts using controlled material deposition technologies has opened up another new area of development - CAM (Computer Aided Manufacturing) [2].

The development of CAD applications for virtual models was also done together with the development of experimental model control applications, that is, with the emergence of applications that could manage both models simultaneously, the real and the virtual. Thus, the idea of digital twin applications (DTs) was born and developed as a very useful tool for both industrial development and modern scientific research [3].

A very wide variety of CAD-CAE-CAM applications have been developed. But not as many as will be developed in the future. The emergence of artificial intelligence has given impetus to the development of scientific research in all areas of human life. And the developments are just beginning. Education will gain new forms of expression and understanding, scientific research will mature through new and advanced methods, computers will evolve to the level of quantum information processing, technologies will develop even faster, robots will become more present, more active, and more per-sonal in use, etc. If you want to learn more, now is the time.

The development of IT applications has reached the point where many decisions are made internally by programs and applications, without direct human intervention, but under certain conditions defined internally by human programmers.

Robots have appeared. They have gained more and more strength, speed, agility, precision, sensors, and even autonomy. But let's go back to our goal for a moment. Machines need to see. So, they need to understand the environment in general and recognize objects as having a particular purpose. The applications necessary for computer vision are constantly developing. This article studies the implementation of innovative methods that use DTs for object recognition and even perform reverse engineering on models if an update of the databases is deemed necessary [4].

Current State

Object detection (OD) is the main concern in computer vision research and involves the correct identification of objects in images or videos, the best possible assessment of the areas that should be considered as part of the object, the most accurate determination of the position of these objects, etc.

Some types of results obtained from object detection are object classification and annotations [5], facial recognition, activity recognition and object tracking [6], detection of the type and counting of vehicles circulating on a road [7], and even results in the field of medical applications [8-11].

Computer vision combined with artificial intelligence is right now transforming the way health assessments are made, how patients are monitored, how medical diagnoses are made, how surgeries are performed, and how medical prostheses are implanted, how the surgical robot detects anomalies in the intervention precision of the medical instrument, how it performs certain automated medical intervention movements, how it differentiates between medical instruments and the tissue undergoing the intervention, etc.[12-14].

Databases for object detection, in most cases, are obtained according to different principles and purposes, with images taken under different shooting conditions, with different objectives and resolutions, randomly selected from different other databases, developed by different people or institutions, etc., which leads to real difficulties in correct segmentation and detection [15, 16].

As detection methods have evolved, so have the techniques implemented inside. Ap-plications have evolved from simple matrix comparisons to ANN algorithms, to feature extraction (CNN), algorithms with segmentation on regions with CNN (R-CNN), One-stage detector (YOLO), Single Shot Multi-Box Detector (SSD), or techniques that use multi-processors and GPUs [17-23].

Other researchers have studied the influence of colors in object detection and the correct detection of colors in the studied images [24, 25].

Evaluating the object's orientation was also another concern of researchers who study object detection [26-29].

From this point research in object detection evolve to estimation of object dimensions, orientation in 3D space and measurement of distances [30-32].

The evolution of object detection techniques will be towards applications massively implemented in mobile phones, as predicted by Mark Zuckerberg, within augmented reality eye-glasses, internet connectivity, and special applications for VIPs (people with visual impairments).

Methodology

This sub-chapter explains some of the methods developed during this research, which have become very complex over the years because of multiple methods implemented for classical object detection, CAD databases and CAD object detection.

Was few research related to OD and CAD models but only for recognition of parts inside complex assemblies [33, 34]. None has attempted to study an update and correlation between OD results and parts or reverse engineering for the CAD model.

CAX technology

What is CAX?

CAX (Computer-Aided Extended) is a set of IT applications, a suite of programming tools that use concurrent engineering to solve multi-objective problems with subroutines that can operate sequentially or in parallel, for a wide variety of requirements: mechanical and strength, durability, comfort conditions, fatigue of materials, for studies with FEM (finite elements model), optimizations, OD, robotics, including with AI techniques and who can manage multiple external applications (EXE, PYTHON, MATLAB, SOLIDWORKS, etc.). So, CAX is currently a state-of-the-art tool in computer-aided technology.

Previous detailed research that studies the OD using DTs and advanced labeling are presented in papers [3, 4, 14]. Basically, this application is a SOLIDWORKS CAD-addon with extended capabilities.

Methodology workflow

Methodology workflow is presented in Figure 1. After reverse engineering, some measure for re-testing at various intermediary steps could be involved.

Custom dataset built based on CAD-Addon use the direction definition based on Euler angles orientation all around 360 degrees the CAD assembly, with a 10-degree step. This means that the custom dataset has 46656 images. Any other images, from real object or other CAD, can be added in the dataset for AI training with specific information related with the object orientation.

The current research also included the development of applications for a wide range of concurrent engineering functions. The method includes:

- CAX type tools;
- Tools for database management and fully automatic database construction,
- Tools for storing models and machine learning (ML),
- Tools for training neural models,
- Tools for OD and result extraction, and...
- Tools for visualizing results, along with much richer information labels than in classic AI programs.

Advantages of using CAX and AI:

- CAX use the full performances of the professional CAD software (para-metric design, smart-assemblies, distance measurements, parts colorization, cutting sections, transparency, animatronics, viewing angles, specific colorization, pattern shading, etc.);
- Images dataset for AI detection is automatically generated by CAX application.

Disadvantages of using AI and Concurrent Engineering:

- Method implemented in CAX are difficult for most researchers;
- CAX methods needed to be developed by users;
- Are necessary professional skills from multiple domains in activity: computer vision, mathematics, engineering, programming, data measurements, CAD, other programming languages, etc.

Redundancy check

Redundancy could be a problem when it exists in many view directions. But this should not be a huge concern because the software reveals the direction with maximum confidence, which is still the best-fit model. To have a reduction in the number of un-necessary images for AI training, could also be performed a redundancy check using a detection with target images from inside the dataset, grouping the images in this way or eliminating de redundant images.

Case Study

This sub-chapter shows few examples for OD using CAD applications with advanced labeling: orientation detection and CAD updating information. Figure 2 reveal the evolution of the OD application from simple detection with orientation (Figure 2 - b) to OD with CAD updating (Figure 2 - c). Initial CAD model has an external radius Re = 1.0 and internal radius Ri = 0.25. After update, recommended dimensions were Re = 1.0 and Ri = 0.34. Radius are considered dimensionless because CAD is a parametric model. But any dimension can be recalibrated if is needed.

Figure 3 shows an OD in an isometric view of torus part position.

Orientation detection reveals also a redundant detection in multiple Euler directions: [-30,0,0], [120, 0,0], [-120, 0,0] with almost identical results in confidence. It can be created a redundancy group for future research. The torus CAD model has many redundancy

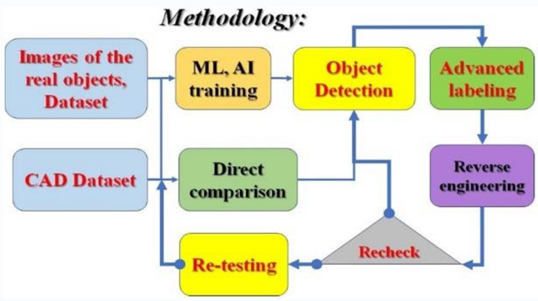

Figure 1: Methodology workflow.

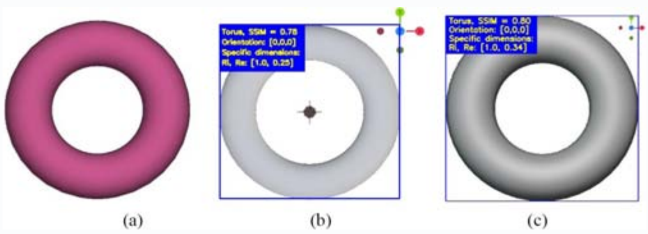

Figure 2: OD and CAD update for a torus part, (a) Initial image, (b) CAD detection, (c) CAD-update.

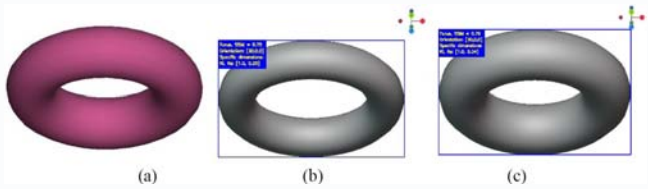

Figure 3: OD and CAD update for a torus part in isometric view, (a) Initial image, (b) CAD detection, (c) CAD-update.

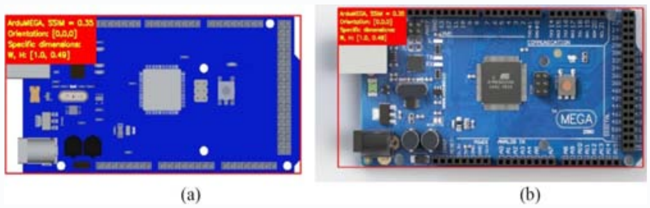

Figure 4: OD on Arduino-MEGA PCB board, (a) CAD detection, (b) CAD-update.

Figure 5: OD on Arduino-MEGA PCB board – isometric view.

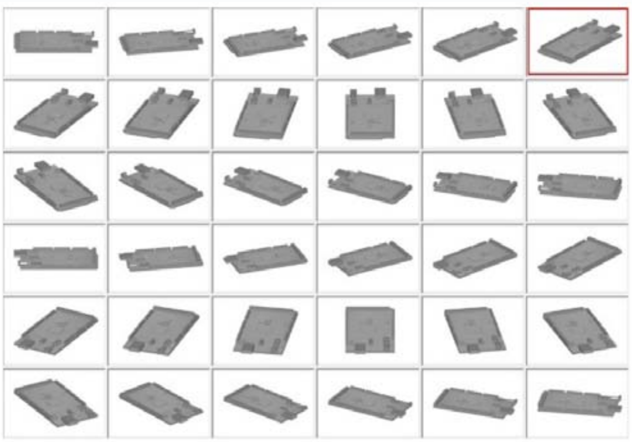

Figure 6: CAD dataset for Arduino-MEGA PCB.

directions. This redundancy does not occur in the case of complex assemblies.

Figures 4 shows OD results on an Arduino-MEGA PCB board and reveal some small differences between size of each model. Figures 5 shows OD results when Arduino-MEGA PCB board is captured in isometric view.

The AI detection can use a CAD database how is presented in Figure 6.

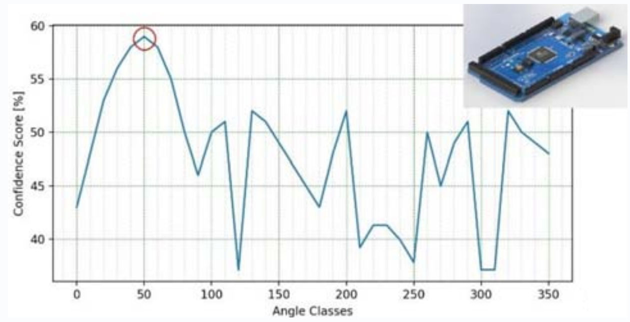

Figure 7: Confidence scores relative to each reference from CAD-set.

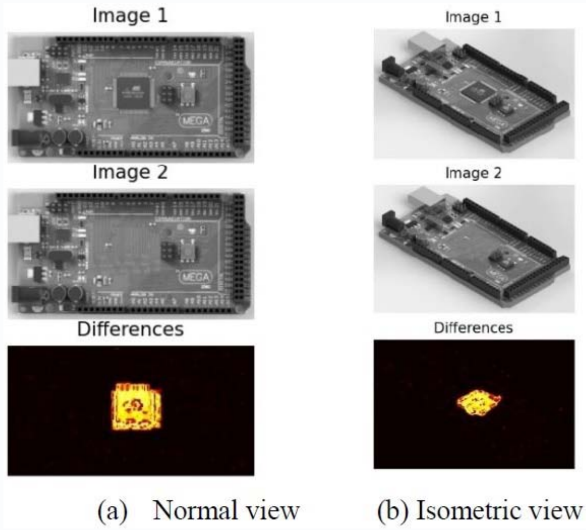

Figure 8: Differences detection over Arduino-MEGA PCB board.

Orientation become AI detection classes. The target image for the test is shown in the upper right corner. Figure 6 shows in the red frame the most likely CAD model and the most correct visualization direction, which gives the highest confidence compared to the target image.

The variation in results confidence by detection, relative to all images from CAD-set can be viewed in Figure 7.

This methodology also includes an artificial intelligence detector for searching differences between captured images of very similar objects, to reveal the defect components on the production lines. It uses the same CAX application with subroutines for evaluating the differences between two or more images (static or from videos) but focusing on the areas of the difference. It can also compare CAD images with real images.

The results from such specific techniques are presented in Figure 8.

The difference detector becomes complicated when there are larger differences be-tween images, most of which do not appear because of the existence of the differences in geometry, but because of the viewing angle. For such errors in CAD models, the best viewing angle and specific object delimitation methods are used.

Better results in comparisons can be obtained using polylines contour like in Figure 9. The method contains crop object, resize at the same scale, edge detection and curve fit, and the area between two

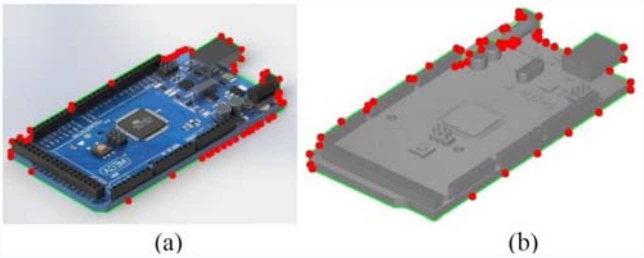

Figure 9: OD using contour. (a) real object, (b) CAD model in the best fit position.

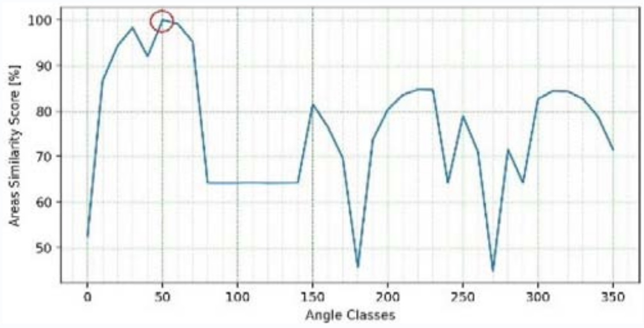

Figure 10: Similarity Score in contour detection.

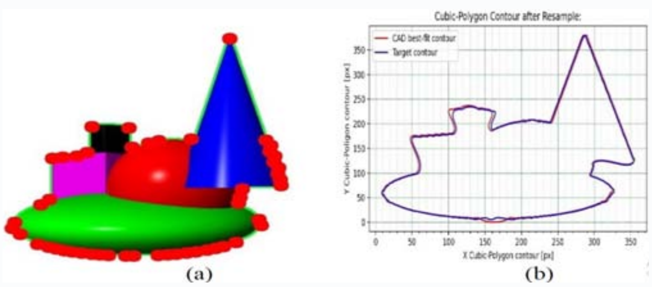

Figure 11: OD using contour. (a) CAD objects, (b) Best-fit CAD model and Target in contour representation.

cyclic curves resampled for the correct integral calculations.

Variation of Similarity Score in contour detection is shown in Figure 10.

Another example for OD in cuboids assembly is presented in Figure 11.

The results in OD using contour over entire dataset for previous assembly model is shown in Figure 12. The Target model is initial model rotated in vertical axis by 42 degrees.

Now, the updating of DTs can be done based on the study of the difference between:

- the outer contours of OD;
- or the difference between two images.

The study of the differences reveals some missing areas in the real model. If we decide to eliminate the black cone, then the results are shown in the Figure 13. Based on the CAD model, we can accurately estimate which component is in the missing area.

These aspects of the study can be done in several ways:

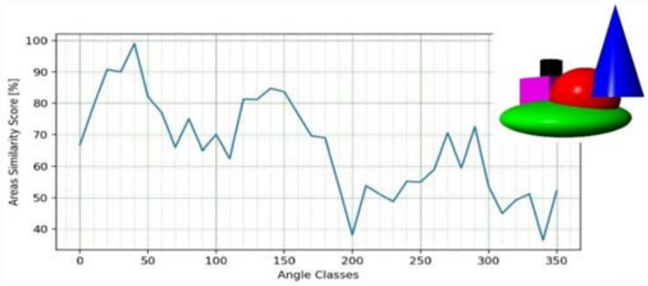

Figure 12: Similarity Score in contour detection.

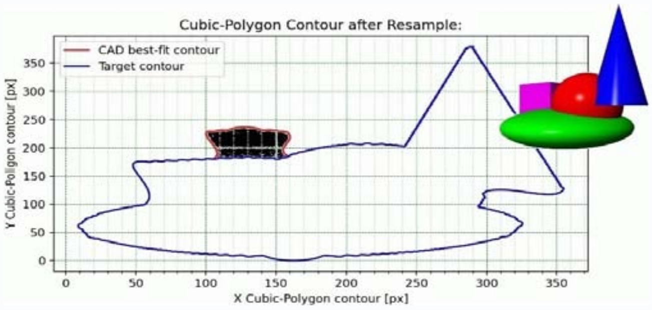

Figure 13: Study of the differences in OD.

1. By the color of the components;
2. By the shape of the components;
3. By the position of the missing area (the best solution).

The position of the mission components can be assessed by:

1. Estimation of the difference between the center of the component and the center of the missing areas;
2. Fit the contour of the missing areas and the contour of the component.

In this study we used the first possibility. The second possibility means studying the differences between the contour of the missing area and the respective component, i.e., applying all the procedures presented in this study once again. This methodology takes longer than the first one.

Conclusions

The key to success in all this research has been concurrent engineering applications.

General observations and advantages:

- OD based contour is much better for object orientation then classical OD based image dataset;
- OD based contour provide more fine results in the right orientation of the objects;
- OD based contour combined with CAD dataset provide precise information about missing or additional parts;
- OD based contour shows good perspectives and promising results;
- OD confidence score depends on the object position and orientation;

- Lower confidence is obtained for orientation with a large inclination relative to the main plane of the part;
- Multiple view detection shows better results;
- Detection and estimation the size of the missing zones;
- Detection and estimation the size of the supplementary zones;
- Using advanced scanners (with laser or light) can give improvements in current presented methods;
- The method can be improved by increasing the order of the powers of the approximation polynomial and the number of interpolation points;
- AI is a research tool and an opportunity for humanity if we are going to use it in a proper manner.

Disadvantages of custom detection methods:

- Precision in CAD correlation with results in detection needs improvements and further research. Supplementary methods and sensors for high-precision measurements need to be implemented together with object detection;
- Was necessary to develop many IT tools for a such research;
- Image quality has influence in OD. A better contrast and illumination im-prove OD, but are not always easy to obtain;
- Some CAD applications may have a perspective viewing switch set by de-fault. This parameter has influence in OD with CAD.

Such a combination of a real model, a virtual one (DT), and a CAX-type application that controls both models through many internal or external extensions and subroutines is a complex AI agent and will represent an important step in future development ac-cording to the requirements of Industry 5.0.

For me, Industry 5.0 is already here, in everything I research:

- Concept design;
- Assembly, engineering and production management;
- Assessment of design and optimizations;
- Recycling and sustainability criteria;
- Advanced materials and meta-materials;
- Advanced competitive engineering applications, CAX technology, AI, intelligent optimization methods;
- Updating and correlating mathematical models with the experimental model;
- Connectivity with all disciplines, advanced CAD models, and intelligent production systems;
- Animatronics, attractive presentations, interactive models, etc.

The complete task of this research was developed based on SOLIDWORKS Educational [35], PYTHON software, MATLAB software, YOLO tool, other internet re-sources [36], and user defined programming routines [37].

This paper presents only some of the more important aspects of our research, with very valuable insights related to how we can use a superpowered DT for OD and the correlation between models.

We can see that AI detection confidence is sometimes not as high as we want. But between ”high confidence with bad classification” and ”lower confidence with right classification”, I prefer the second choice.

It is obvious to me that creativity will partially transmute from human abilities to those of computing machines. But, even so, we can learn from here, from these lessons of technological steps.

Interest in Future Research:

- Updating DTs requires more research related to measurement accuracy;
- Auto-adaptive tool for Object Detection;
- A combination between methods presented herein and advanced tools for scanning real parts [38];
- Filtering of the contour data as a combination between polynomial points information and images segmentation;
- Still needed research for the correlation between 2D and 3D orientation, because each method is based on different techniques.

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