

A Vision Based Audit Method and Tool that Compares a Systems Installation on a Production Aircraft to the Original Digital Mock-Up

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ABSTRACT

The work describes a concept application to aid a safety engineer to perform an audit of a production aircraft against safety driven installation requirements. The capability is achieved using the following steps:

- A). Image capture of a product and measurement of distances between datum points within the product with/without references to a planar surface*
- B). A digital reconstruction of the fabricated product by using multiple captured images to reposition parts according to the actual model.*
- C). The projection onto the 3D digital reconstruction of the safety related installation constraints, respecting the original intent of the constraints that are defined in the digital mock-up.*
- D). Identification of the differences between the 3D reconstruction of the actual product and the design time digital mock up of the product*
- E). Identification of the differences/non conformances that have a relevance to safety driven installation requirements with reference to the original safety requirement intent.*

Step 'A' gives the safety engineer a means to perform measurements on a set of captured images of the equipment they are interested in. Steps 'B', 'C', 'D' and 'E' together give the safety engineer the ability to overlay a digital reconstruction that should be as true to the fabricated product as possible so that they can see how the product

conforms/ or doesn't conform to the safety driven installation requirements. The work has produced a concept demonstrator that will be further developed in future work to address accuracy, workflow and process efficiency.

1. INTRODUCTION

In the early design phase, the systems installation is defined by geometrical 3D models (the digital mockup (DMU)). The DMU approximately defines the shape, the size and the location of each of a systems equipment and routings within the aircraft structure. Through the evolution of the design process, the 3D models become more accurate, eventually giving the shape of the detailed product. The DMU is used to manufacture the individual parts. These models are ideal representations of the systems installation (they do not take into account flexibility due to gravity, etc.). At every design phase, the installation needs to satisfy various geometrical requirements originating from various disciplines. One such discipline is safety analysis. Common Cause Analysis (CCA) is a part of the aircraft systems safety analysis as defined by SAE ARP 4754 and SAE ARP 4761. CCA generates a number of derived requirements that impose installation constraints that must be respected. During design time, this simply means ensuring that the geometry model has constraints such as segregation, proximity, and orientation defined that represent these installation constraints and that the installation constraints are respected. When the aircraft is fabricated, it is crosschecked against the design model for correctness using various measurement techniques. This paper describes a new comparison technique that potentially could help in reducing the duration to perform a large number

of measurements and at the same time ensure that all measurements performed can be formally documented. The work involves the customization, development and use of a set of image processing based tools that take multiple images of the fabricated product and use these images to create a digital reconstruction. The digital reconstruction is loaded into the same environment as a point cloud representation of the digital mockup and a comparison is made possible. A constraint on the project was that a single hand held camera should be used without any other projection equipment. The paper finally presents the level of accuracy that was achieved during the project and briefly proposes directions of investigation that may lead to the tools achieving the required levels of accuracy.

2. BACKGROUND

Various techniques exist that can be used to perform 3D measurements such as:

1. 3D scanning systems are used to capture the point clouds by using a laser-based range finding technique. The point clouds are then used to analyze the given environment [11].
2. 3D measurement can be achieved using **viewpoint coded structured light** generated by some means of projection to reconstruct the 3D shape of an object [10]. Three cameras are used to obtain multi-frequency fringe images. **Phase shifting** and **multi-frequency heterodyne principles** are applied to the images in order to enable measurement.

Most of the industrial components such as pipes, wires are not well textured which makes feature detection and matching cumbersome for image processing techniques. Likewise dark or highly polished surfaces of the subject matter make laser based ranging techniques very noisy.

The approach that was developed in this project was based on image processing techniques that are assisted by user intervention to identify common features where they are not immediately apparent due to the lack of texture.

Various techniques exist that can be used to perform comparisons between a product design and the fabricated product.

The comparison between a product design and the fabricated product can be achieved using geometric models and point clouds [12]. There is a wide body of literature that covers model matching, however the work that is the most relevant to the research is discussed in Georgeli et al. 2007.,

1. The authors [2] propose an augmented reality solution for discrepancy checking in order to identify the differences between the planned 3D model and built items. Initially, anchor plates are used as reference information to obtain the orientation in the coordinate system of the 3D model. Once the orientation is obtained, an augmented CAD model is

created by positioning the image into the 3D view. Upon positioning, a transparency level is used to view the deviation, which is achieved using 2D information.

2. Indeed, there are few commercial application like that produced by Geomagic, [13], which attempts for quality inspection using CAD matching and scanned point clouds.

As mentioned earlier, unlike existing works, the distinct nature of our work is that a) we use 3D information from multiview images, b) we use semantic metadata knowledge available from geometry models and c) discrepancy analysis in order to perform the comparison between the design model and the fabricated product.

3. OVERALL OBJECTIVE

The core objective of the task is to design and implement a Production Safety Audit capability that can help the safety engineer:

1. *Identify and take an accurate enough relative measure of the position of the various objects present in multiple image captures of a set of equipment, with respect to some datum and to each other, thereby aiding in the quality and safety inspection*
2. *Identify configuration differences between the DMU and the captured fabricated product.*
3. *Link the inspection task and audit results to the safety related installation requirements.*

For the purpose of the work in the MISSA project image processing techniques were used with the

1. *3D Measurements from images just using points of interest and calibration information. There are various means to measure distances between identified objects, distance with respect to planar surface etc.*
2. *Stitching together multiple scans to form a composite scan of a region of interest.*
3. *Identification of basic geometric shapes from the scan data such as: Points, Planes*
4. *Various filtering tools to clean the data set from noisy data.*

3. DESCRIPTION OF THE WORKING ENVIRONMENT

There are restrictions that need to be considered while performing measurement and testing within the complex installation environment. The safety engineers make measurements within areas where access or space is limited, limited exposure of light, no exposed sparks, low power *etc.* Furthermore, there should not be any permanent markers and no systems that might have an affect on Health and Safety here

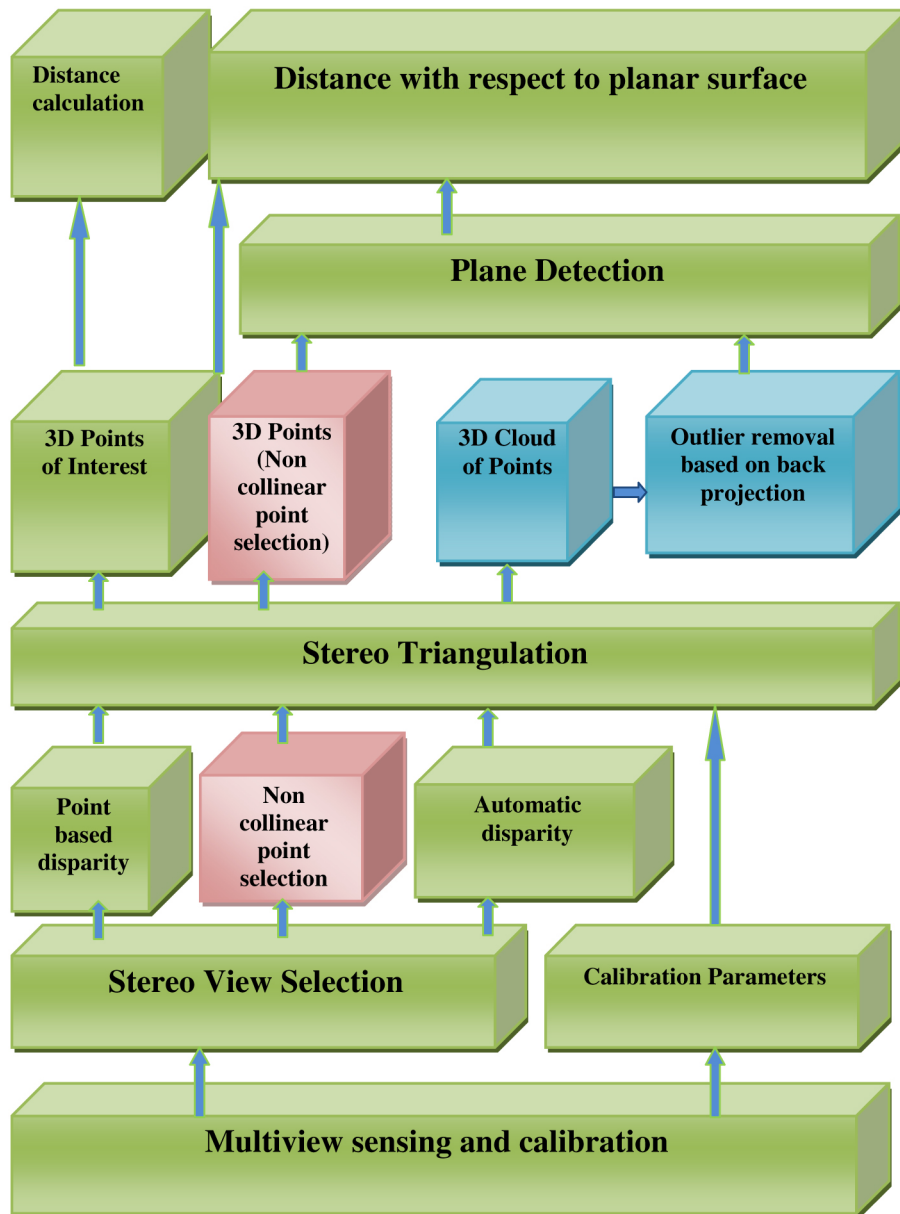


Fig.1. MISSA 3D Measurement and Auditing Framework Block Diagram

allowed. People cannot be captured as well. Hence equipment used for safety measurement should consider the above requirements. As such only photographic techniques using low cost cameras were considered. The amount of effort involved is much less in terms of the logistics required to use a camera when compared to using scanner solutions.

4. OVERVIEW OF THE TOOL

A tool was developed that achieves the objectives described above. The tool contains capabilities for 3D measurement audit and model comparison that uses inputs from a digital camera and semantic metadata knowledge available from the geometry models, which can be used for the verification tasks. The next section describes the framework and a

selection of the components that make up the framework in some detail.

5. ELEMENTS OF THE TOOL

The tool is composed of two parts, the first involves providing means to perform measurement and the second involves providing a model matching capability.

5.1. 3D MEASUREMENT

The framework for 3D measurement is presented in Fig. 1. The unique features of the 3D Measurement tool are the automated calibration utility, the zoom in option (to help selecting points accurately) and optimal combination of point

based disparity and Local Invariant Feature Extraction (LIFE) based disparity which complements each other. These two techniques enable the measurement between any combination of two points, as well as the distance between any points and the perpendicular distance to a defined plane. The framework contains two distinct functionalities. The first functionality is where a user provides points of interest with which distance constraints need to be checked. The second functionality is to get a reasonable 3D cloud using automatic correspondence to facilitate planar surface detection. At this level, we perform outlier removal based on back projection to ensure only correct 3D points are retained. A reference plane is detected using a non-deterministic algorithm, such as RANSAC(Random Sample Consensus). It is an iterative algorithm for estimating the parameter of a planar model from the 3D cloud data points. We thus obtained the 3D distance with respect to reference planar surface to any user points of interest. In summary, the distance between any datum points is found and also distance between any chosen point and planar surface is estimated in a given installation environment at mm level accuracy.

Point based disparity:

Point based disparity is based on each of the points identified from in two images that show a different perspective of the same scene. While selecting points, first the user is shown the left image where they select the point coarsely (refer Fig.5 (a)). Then, the system shows the point location on left image that is zoomed so that the user can select the point location very accurately (refer Fig.5 (b)). Similarly, a user will be shown the right image where they will select the point coarsely. Then the point location on the right image will be zoomed so that the user can select the point location very accurately. Since disparity is obtained manually, there is no need for outlier removal and mm level accuracy can be achieved.

Automatic disparity: This is based on Local Invariant Feature Extraction techniques such as SIFT [7], SURF [8] etc. The advantage of this method is its invariant capability towards translation, rotation, scaling etc.

3D Stereo Triangulation: As stated by Izquierdo et al 2003 [3], two corresponding points represent the projection onto the image planes of the same object point. The 3D position is the intersection of both viewing lines and can be estimated using the coordinates of its projection in both images and the camera parameters. Triangulation is a process of determining the location of a point by measuring angles to it from known points at either end of a fixed baseline, rather than measuring distances to the point directly. The point can then be fixed as the third point of a triangle with one known side and two known angles. The 3D point X shown in Fig.2 can be

retrieved from observed projection m_i and n_i onto the image planes.

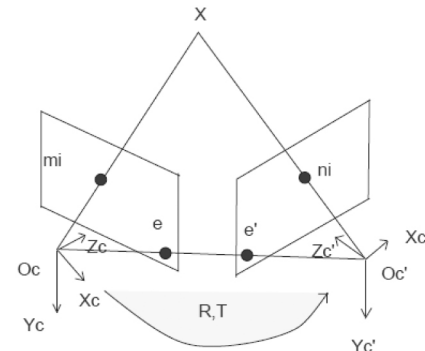


Fig.2. Epipolar stereo geometry

Plane Detection:

A plane can be defined just using 3 non-collinear points. The user is required to select 3 non-collinear points in the stereo images in order to obtain the plane. The system of equations ($ax+by+cz+d=0$) with the selected points can be solved using Cramer's rule. The parameters of the plane in its normal form (refer Fig.3) can be obtained as:

$$\theta = \tan^{-1}(b/a)$$

$$\phi = \tan^{-1}(-\cos(\theta)/a)$$

$$\rho = c * \sin(\phi)$$

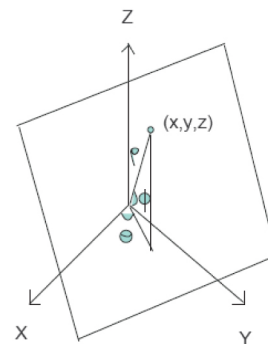


Fig.3. Representation of parameters of plane in its normal form