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Highly Accurate and Portable 3D Surface Analysis Tool (APSA) for Printed Circuit Boards (PCB) Reconstruction and Assurance

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With the growth of computational capacity, improved cloud infrastructure, and Artificial Intelligence (AI), PCBs are now omnipresent; ranging from private sector computers, servers, and handhelds to public sector military and medical equipment. Outsourcing PCB manufacturing makes the boards vulnerable to malicious modifications from external entities [1]. For instance, hardware Trojan insertions enable backdoor access to highly sensitive networks and potentially compromise the infrastructure of entire nations including its military capability and civil safety [2, 3]. Thus, PCB quality and security assurance are an important contemporary need.

PCB Security and Assurance is currently performed by human operators using Digital Optical Microscopes (DOM), X-Ray Computed Tomography, and other imaging modalities. This process is time-consuming, expensive, and prone to human error. But new and innovative computer vision algorithms can automatically extract essential details about the PCB, its components, location, dimensions, and its authenticity to present it in universally understandable formats such as Bill of Materials (BOM) and 3D Models (PLY, 3DS). In addition to companies, the solution should also be accessible to end users; This is the goal of automatic bill of material extraction [4] i.e., to make PCB assurance, accessible, inexpensive, and secure. Using 2D optical images to generate a BOM cannot provide close fitting contours of components, making it difficult to measure its dimensions. Adversaries are getting smarter [5] and Trojans could be replaced by visually similar components that vary in dimensions to modify functionality or sabotage the system [6]. Thus, 3D imaging modalities have become a necessity to address PCB assurance.

Commercially available imaging modalities include white light, laser interferometry, and structured light-based detectors. However, these devices have their benefits and drawbacks. Key players like Keyence [7] and Cognex [8] provide Laser profilers, 3D Interferometry systems, and wide area scan systems but they are expensive, require an additional cost for setup, and software packages. These systems are fixed [8] and require high precision XY Stage to measure accurately [7], and they can image only top-down. CyberOptics produces end-to-end AOI systems [9] that are fast, accurate, and built specifically for PCB Assurance. However, they require a human operator, are bulky, and very expensive.

Our novel solution utilizes multiple images taken from varying directions and distances to build a 3D model (Multi-view Photogrammetry) for PCB measurement and assurance. Analysis is flexible on input data, affordable, and even images taken in mobile phone or Digital Single-Lens Reflex (DSLR) cameras with 1920x1080p are sufficient for 100um resolution in measurements and evaluations. A DOM will provide even increased resolution and accuracy.

The proposed method consists of: (i) Image Acquisition and Reconstruction; (ii) 3D Processing; and (iii) Analysis. In the first stage, images are collected using the modality of choice, shown in Figure 1. Since components are small and densely packed in PCBs the camera should be 150mm or closer, for a 100um resolution. Acquisition is done using a DSLR camera with 32 images 1920 x 1080 pixels in size. 3D reconstruction identifies features and matches them, so image clarity is vital. While a DSLR's auto-focus helps, this problem may arise for other modalities. Thus, once the images are collected, image quality for distortions and loss of focus is tested using Blind image assessment techniques [10].

3D Reconstruction is done using dense object reconstruction methods [11] but processing a PCB point cloud is challenging. Identifying the PCB board plane in a dense point cloud requires multiple algorithms and side/auxiliary information. Firstly, denoising is performed to remove flying points characteristic of photogrammetric methods. Next, the PCB board is isolated with a key insight- PCB board is the only plane that is a natural solution to a plane fitting over the PCB point cloud. However, there is still an impact of noisy outlier points, so we employ Random Sample consensus (RanSaC) to identify the board plane amidst noise. With the board identified, components that do not lie in the board plane are isolated. At this stage, additional data such as the smallest component in the PCB under test, minimum distance between components, and length of the PCB is required to determine the minimum point-cluster size, to distinguish closely placed components and to translate the relative dimensions in the point cloud to real-world dimensions, respectively. Multiple levels of clustering are done based on the Euclidean distance metric and the clusters are filtered based on smallest component information; Analysis is then performed for height and dimensions. For our study, component height is the key objective because it cannot be obtained using 2D imaging methods, however the length and width can also be trivially obtained at this stage.

We have presented a novel approach using affordable, handheld imaging systems to model and perform analysis on PCBs. The segmented components, the dimensions, the board layer, etc. compiled into a BoM can be used for comparison with golden BoM to find malicious modifications. General purpose reconstruction algorithms used in the study are prone to loss of data in regions of low features (IC surface or shadows). Our future works will focus on building a custom 3D reconstruction algorithm specifically for PCBs. Using the robotic arm to iteratively image regions will prevent dark regions and overshadowed components. This also provides a location prior, helping increase the reconstruction speed. In addition to PCBs, our approach can be applied to various other quality assurance scenarios, such as mechanical parts inspection or remote sensing to reconstruct buildings and objects in satellite imagery.

Figure 1. Figure 1: Digital Optical Microscope (left) for high resolution imagery, DSLR camera for Quick and Affordable Imaging (middle), and Robotic Arm for faster and iterative reconstruction (right).

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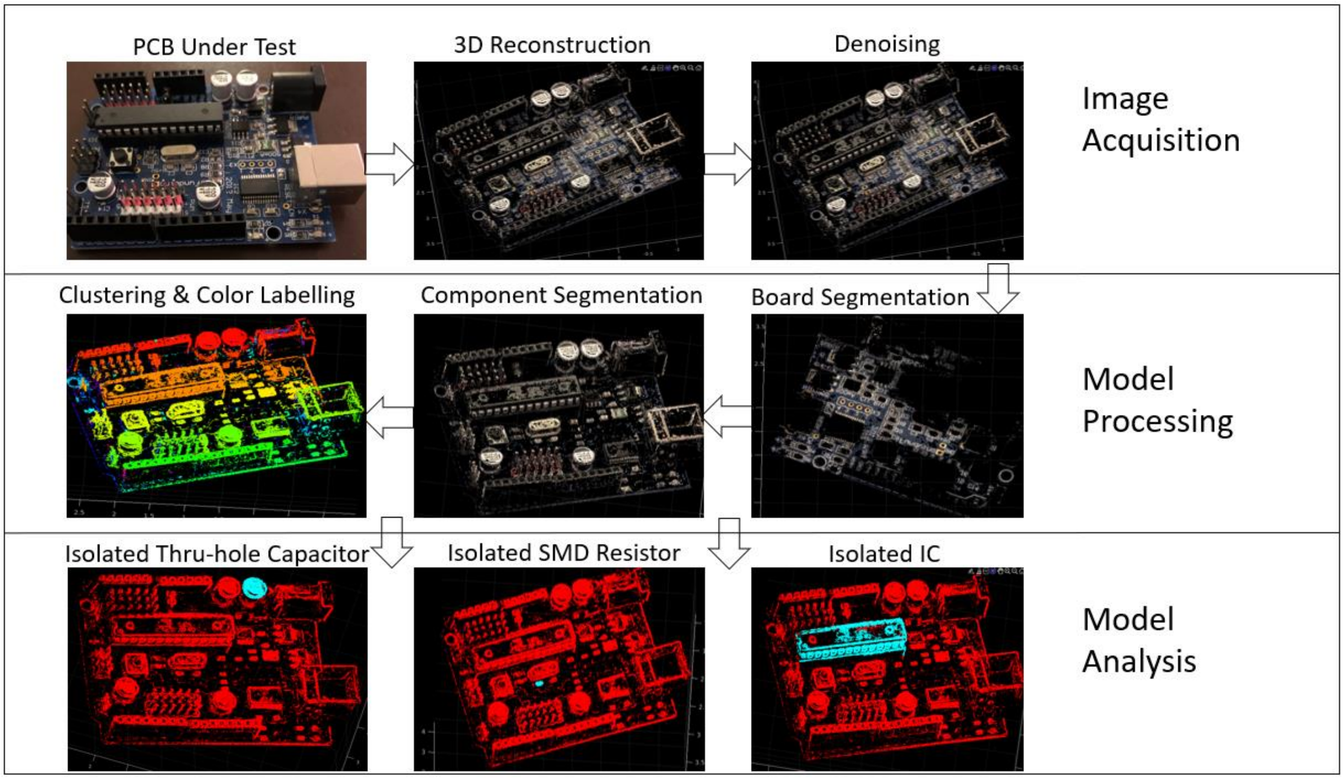

Figure 2. Figure 2: Multi-View Photogrammetry for PCB Modelling and Analysis explained: From 32 Images of PCB under test, reconstruction, and denoising is performed during the image acquisition phase (Top Part – First Stage). Plane fitting to identify PCB board and segmenting based on side information is performed during the Model processing phase (Middle Part – Second Stage). At this stage individual components are clustered. During Model Analysis, the clusters are filtered, and their height is measured (Bottom Part – Third Stage).

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