Test and measurement automation of printed circuit board assembly using digital oscilloscope

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Article Info

Article history:

Received Sep 28, 2023
Revised May 23, 2025
Accepted Jun 10, 2025

Keywords:

Automation
Digital oscilloscope
Industry 4.0
Printed circuit board assembly
Test and measurement

ABSTRACT

The testing and measurement (TM) of electrical parameters of printed circuit board assembly (PCBA) plays an integral part in the manufacturing sectors. These industries work on embedded system which widely use digital oscilloscopes (DO) for such purposes, however, operate them manually. An exponential rise in the implementation of industry 4.0 with the increasing demand for industrial products makes manual TM cumbersome. The automation of oscilloscopes (AO) remains a viable alternative to these issues requiring further investigation. An accurate and automated TM block facilitates efficient design, development, and assembly of a fully functional system hence addressed here. The AO has been carried out using generalized software that can be configured based on industry requirements. It subsequently stores the data on the server for better traceability. The automated software is developed using VB.NET and installed on a personal computer. Experiments reveal the proposed approach saves approximately 60%-70% of the time required for each PCBA operation than that of the manual system. This can enhance the productivity of the industry in terms of manpower and Resource utilization with a reduction in operating costs.

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1. INTRODUCTION

In electronic circuitry, printed circuit board assembly (PCBA) need to undergo testing to ensure functionality and meet quality standards. Numerous industries are transitioning towards industrial automation, testing thousands of PCBAs daily for parameters like sensor values, signal amplitude, frequency, and rise and fall times. Common tools for this purpose include the digital oscilloscope (DO) and the multimeter. Manually testing large numbers of PCBAs is both time-consuming and challenging. Factors such as technological advancements across various fields and increased production demands drive the shift towards automation testing. Automation offers significant advantages such as reduced labor, energy consumption, and material usage, while also improving quality, precision, and accuracy [1]. The term "industry 4.0" (I-4.0) refers to the fourth industrial revolution's utilisation of digital technologies and capabilities. It aims to create highly digitalized and interconnected smart factories and supply chains consisting of cyber-physical systems. The concept of I-4.0 and smart factories are triggered by changes in the general social, economic, and political landscapes, as well as an increasing technological push in industrial practices. With increasing capabilities like the internet of things (IoT), 4G, and 5G technologies, I-4.0 is promising potential benefits such as shorter development time, flexibility, individualization on-demand, and improved resource utilization [1]. The technological pillars of Industry 4.0 are mainly digitized concepts like big data analysis, autonomous robots, simulation, horizontal and vertical system integration, industrial IoT, cyber security, cloud computing, additive, manufacturing, 3D printing, augmented, and virtual reality [2]. The journey from Industry 1.0 to Industry 4.0 is shown in Figure 1. To achieve the mass production of complex PCBs effectively, it is essential to integrate automated test equipment (ATE) into the manufacturing process [3]. It facilitates capturing the signals from each test point automatically, validating the results, storing, and updating the remote server. This will ensure traceability and optimize resource utilization.

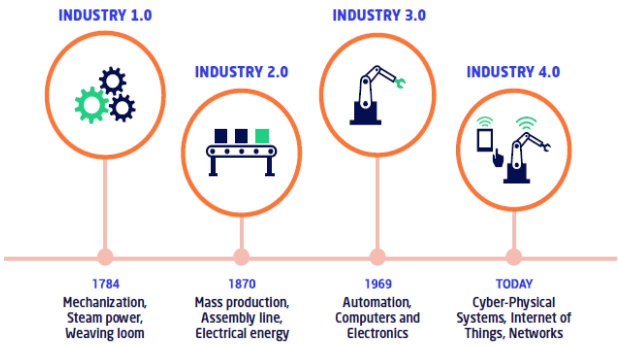

Figure 1. Industry 1.0 to 4.0

The testing of components amounts to 30% of the overall manufacturing cost, hence the methods chosen for testing need to be selected judiciously [1]. Among several testing strategies in practice, this work focuses on an improved functional testing approach that can overcome the difficulties posed by other techniques**.** The proposed method employs instruments that are managed by software to test a PCBA unit. The settings required to be done in the oscilloscope for each test will be stored in a server that is configurable based on requirements. Signals from PCB assembly, such as voltage, current, and impendence, are precisely analysed by the requirements of each test. Then the results will be compared against server data and it will automatically be checked whether the test is passed or not. Automation of such processes provides huge test coverage and limits the factor of time.

2. LITERATURE SURVEY

Typically test and measurement of electronic components in a PCBA play an inevitable role in the quality of functional testing. To overcome the problems which are faced while manual testing of PCBAs, Automated testing is desired. The measurements accomplished by instrumentation comprise a crucial part of electronic testing by ATE [4]. Advanced measurement capabilities of modern instrumentation such as digital storage oscilloscopes make them extremely powerful, but also add significant complexity due to manual operation [5]. The automation of the processing of images using an oscilloscope with LabVIEW software has been reported in [6]. The authors have provided the means of electrical signal acquisition, a processing system focusing on the front panel of the oscilloscope to process waveforms [7]. The virtual instrument software architecture (VISA) over a local area network (LAN) was used to design a remote automatic test system in the MATLAB application development environment (ADE) [8]. The integration of microwave imagining tests and DO have been explored to test radio frequency and intermediate frequency signals. Similarly, the integration of MATLAB, LabVIEW, and the development of calibration software for frequency generators has been used to support the IEEE-488 bus standard [9]. an implementation scheme of applying LABVIEW to build a user interface to control two oscilloscopes remotely and acquire data via a network has been investigated [10], [11]. Software testing could be a method of finding errors while executing a program. It is aimed at evaluating the potential or usability of a program and is vital for accessing the quality of software systems [12]. Most of the tools of automated software testing increase reliability and performance, allow the tester to repeat and reuse the final product, saves labour, time, energy, and materials, and improve quality, accuracy, and precision [13]. The virtual bench instrument combines a mixed-signal oscilloscope with protocol analysis, an arbitrary waveform generator, a digital multimeter, a programmable DC power supply, and digital I/O [14]. The all-in-one features are simple, and convenient, and provide more efficient circuit design, debugging, and validation. The virtual bench instrument easily integrates with LabVIEW software to provide programmatic control and automated test sequences [15].

According to Saikia *et al.* [16] in a stereotypical view, SQL server is considered to be an enterprise-level tool; MySQL has carved a niche as a backend for website development. This paper is an attempt to set a benchmark in comparing the performance of MySQL against SQL server in a Windows environment [17]. In this regard, visual basic network (VB.net) enables a new version of a simulation industry populated by application-specific simulation specialists which generate compatible and reusable simulation components [18], [19]. Interchangeable virtual instruments (IVI) drivers work best in standard object-oriented ADEs that support COM directly or through some interoperability mechanism. IVI drivers are more sophisticated instrument drivers that feature increased performance and flexibility for more interactive test applications that require interchangeability [20]. General purpose interface bus (GPIB) was developed as an interface between computers and measuring instruments. It can be used to transfer data between two or more devices. Handshake communication allows GPIB to achieve highly reliable data transmission. GPIB interface is employed by many measuring instruments, allowing users to control a variety of measuring instruments by mastering a single protocol. GPIB devices with different communication interfaces, maximum speeds can be attained [21]. Data storage essentially means that files and documents are recorded digitally and saved in a storage system for future use. Data storage makes it easy to back up files for safekeeping and quick recovery in the event of an unexpected computer crash. Data storage can occur on physical hard drives and disk drives. Some data storage tools are Cloud, MySQL, and MSSQL [22]. Cloud storage is a cloud computing model that stores data on the Internet through a cloud computing provider that manages and operates data storage as a service [23]. It’s delivered on-demand with just-in-time capacity and cost. Complete cloud-based or online storage solutions offer virtual data storage and convenient access anywhere.

3. METHOD

The work covers the use of VB.NET-based software to automate DO procedures. The workbench setup for testing and analysis of the electrical signal from the chosen PCB assembly is shown in Figure 2.

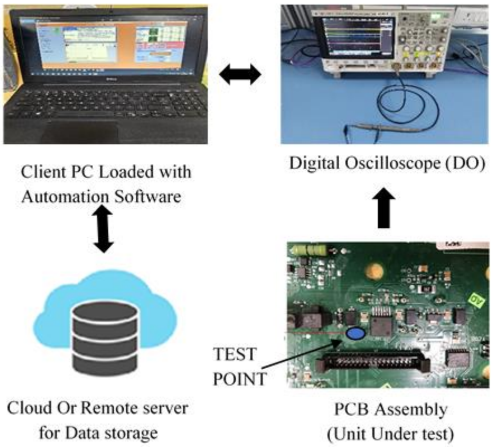

Figure 2. Workbench setup for PCB assembly testing using DO

The proposed methodology comprises the following sub-modules, as explained below:

- PCB assembly: this is the unit under test, with test points as per the requirements. These test points provide access to capture the signals from capacitors, resistors, voltage regulators, ICs, and diodes. When the DO is connected via an oscilloscope probe.
- DO: a DO processes electrical signals from the PCB assembly and displays them on the screen. It provides several signal characteristics such as amplitude, time, frequency, mean. The DO is connected to the client’s PC via USB [24].
- Client PC: the electrical test automation software (TAS) will be installed on the client PC and will be used to remotely control the DO to record and measure the signals from the PCB assembly test points. The client PC is connected to the server via LAN.
- Cloud/remote server: it can be placed either remotely within the factory premises or on the cloud, based on the user's requirements. This carries the details of the oscilloscope settings and results of each test performed on the PCB assembly. Client PCs will access the server based on requirements using a LAN.

Figure 3 shows the proposed workflow and steps for the test automation setup to test the PCB assembly. This system is designed to be general-purpose and configurable to make it compatible with different PCB assemblies.

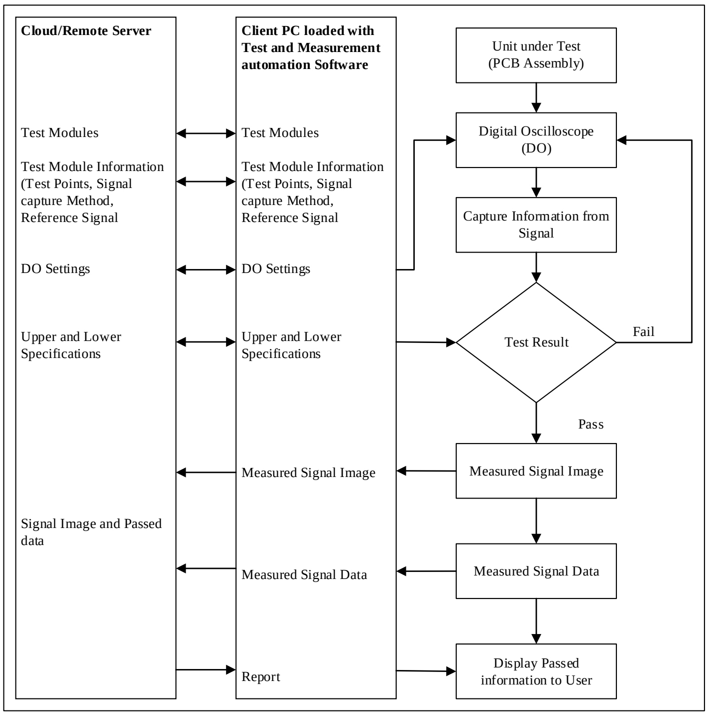

Figure 3. The proposed PCB automation testing flowchart

3.1. Test and automation software

The PCB assembly testing is carried out at bharat electronics limited (BEL) using this specifically developed electrical TAS. This software facilitates users to test PCBs (logic and interface boards) of voter verifiable paper audit trail (VVPAT), control unit (CU), and ballot unit (BU). To use the developed electrical TAS, the Keysight connection expert application should be installed. To work with the TAS, a LAN and USB connection between the DO and PC/laptop are required. Figure 4 shows the electrical tests application's front panel, which includes options such as admin, CRO details, help, and reports. The user can change channel settings using the admin option, however, to do so, the user must input the admin password. DO details, including VISA addresses, can be added with the help of the CRO details option, while the Help option allows the user to contact the developer for queries.

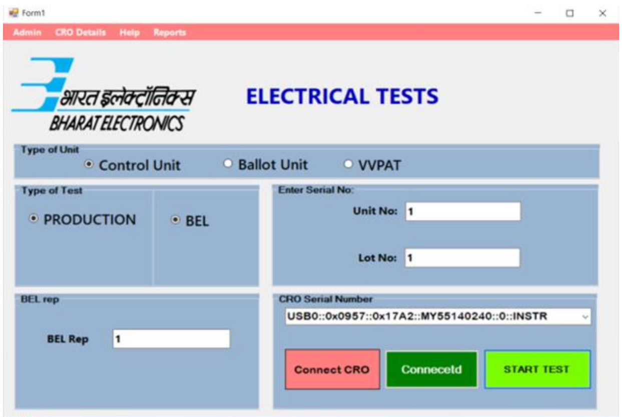

Figure 4. Front panel of electrical TAS

3.2. Printed circuit board electrical test procedure

The Login Window of the electrical TAS displays the type of unit, type of test, enter serial no., BEL rep, and CRO serial number. The following are the possible choices for carrying out a certain PCBA test.

- Type of units: this section contains CU, BU, and VVPAT.
- Type of test: this contains production and BEL.
- Enter serial no.: it includes unit no. and lot no.
- The BEL rep: BEL representative's name should be entered here.
- CRO serial number section: contains the VISA address of the oscilloscope.

Open the Keysight connection expert program, where the VISA address will be visible in the USB section, to verify the address. A green tick indicates that the desired communication has been established between the oscilloscope and PC/laptop, while a red tick means that the oscilloscope has not been detected. The connect CRO and START test options enable the successful connection and testing of PCBs. If the connection fails, the connect option will turn red. While clicking "START TEST" opens a new window containing the CU electrical tests. Table 1 provides the subsections of the CU electrical test window.

Table 1. Electrical tests modules and sub-modules

Test details	CRO settings	Settings	Results
Test description, test points, result channel, measurement method, minimum, and maximum unit.	X-axis, Y-axis, coupling, offset, trigger type, trigger level, time delay, probe Attn. impedance, and mode.	SET, expand, STOP, RUN, Delay +ve, Delay -ve, single, offset, offset +ve , Offset -ve.	Measured values with pass/fail status.

For instance, the parameters chosen in the proposed CU electrical TAS and the testing procedure of the ‘CU’are provided below:

- Type of unit: CU.
- Type of test: production and BEL.
- Enter CU unit no, lot no, and enter BEL Rep name.
- Select CRO serial number (VISA address) which is detected by Keysight connection export.
- Click on connect CRO option.
- Then begin the test. In the electrical test software, the user selects the module name (self-diagnostics CSA, battery CSA, RS 485—RX & TX.) and the test no. (7.1.2) of the test to be performed.
- CRO settings will be displayed after selecting the appropriate test number.
- Set the CRO channel settings by clicking the SET option.
- Connect the probes to the respective test points, then follow the measurement method to capture the waveform.
- As you click "Measure and Save" the measured parameters (Pk-Pk voltage) are compared with the threshold values, and the results section will display whether the test passed or failed along with the measured data.
- The output waveform will be saved in both the server and client PCs together with the measured value.

A server is required to run the TAS software in which all the oscilloscope settings are saved. The software is connected to the server using LAN. The channel settings contain channel numbers, the values and units of the X-axis, Y-axis, offset, and trigger. depending upon the test to be performed. After measuring and saving, the output parameters are compared with the chosen threshold values which are in the database. It notifies whether the test is passed or failed depending upon the compared values. From the resulting waveform, different types of measurements can be analyzed.

Following are the measurements that can be performed using the developed TAS software. Horizontal-axis measurements as shown in Figure 5. Vertical-axis measurements as shown in Figure 6.

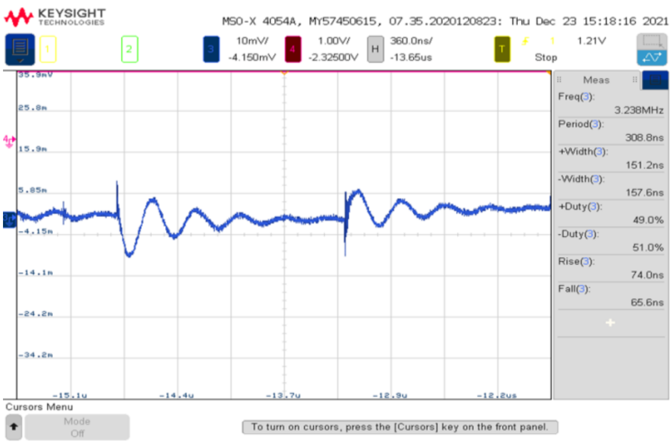

Figure 5. Horizontal axis measurements using the proposed TAS software

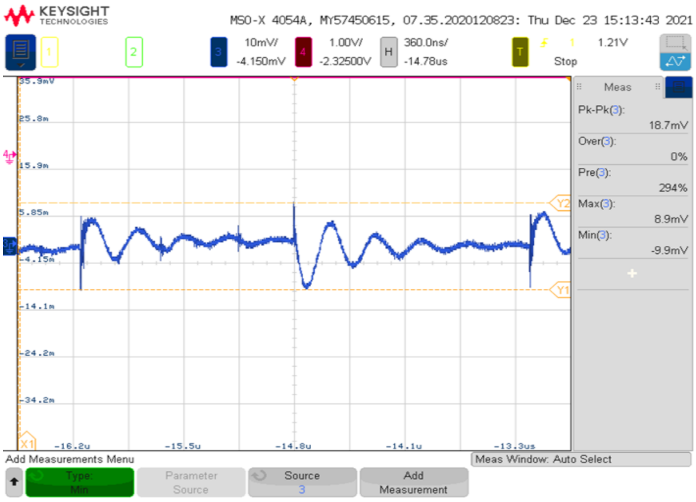

Figure 6. Vertical axis measurements using the proposed TAS software

4. RESULTS AND DISCUSSION

An investigation has been carried out in this work to measure the mean and rise time of a signal using the developed TAS software. Oscilloscope settings (9 common settings), capturing the waveform, and taking the measurement require approximately 13 minutes for the mean and 6 minutes for the rise time in a manual setup. Contrarily, as seen from our experiment, the time in the proposed system is reduced to 4 minutes for the mean and 2 minutes for the rise time. Considering the large number of PCBAs subjected to testing and measurement (TM), such an automation approach can save a considerable amount of time and labour as compared to the manual testing method. To validate our claim, the work provides a case study, as briefed below.

Let's consider a case study of PCB assembly testing at BEL, Bangalore, India, where the experiment has been carried out. The BEL laboratory tests thousands of PCB assemblies, such as CU, BU, and VVPAT. The proposed work considers the three major units, such as CU, BU, and VVPAT to validate the developed TAS software. In the PCB assembly testing of these units, there are more than 205 testing points. Several components, such as voltage levels of regulators, sensors, battery, LED, and RS-485 TX and RX are tested and measured both manually and using the developed TAS software in all the chosen units of different PCB assemblies.

A comparison of time for manual and automation testing (using TAS software) has been made for different modules of VVPAT in Table 2. There is a considerable saving in time without any computational errors using the proposed TAS software as compared to the conventional manual testing system, as observed from the above table. Additionally, there will be many calculations and ambiguous connections made during the manual testing of these PCBs in bulk, in addition to inherited human faults [25]. This study shows, the TAS software is three times computationally more efficient than the manual testing procedure.

Table 2. Comparison of time for manual testing and automation testing for different modules of VVPAT

Type of test	Manual (mins)	Automation (mins)	Savings in time (%)
9 V SMPS regulator	40	13	67.50
7.5 V regulator	28	10	64.29
3.3 V regulator	28	10	64.29
(-)3.3 V regulator	35	12	65.71
Battery CSA	30	10	66.67
CSA self diagnostics	50	20	60.00
Battery impedance	25	10	60.00
e -FUSE	95	30	68.42
Length sensor	80	30	62.50
Deplete sensor	55	20	63.64
Contrast sensor	125	40	68.00
Fall sensor	60	25	58.33
RS-485 RX	25	10	60.00
RS-485 TX	25	10	60.00
RS-485 D-RX	22	8	63.64
RS-485 D-TX	21	8	61.90

Figures 7 to 9. provides the detailed graphical analysis corresponding to three different testing projects such as VVPAT, CU, and BU considered in this work. The significance of testing projects like VVPAT, CU, and BU extends beyond technical functionality; they act as bulwarks against electoral malpractice and manipulation. By subjecting these systems to rigorous testing protocols, electoral authorities can pinpoint vulnerabilities and implement necessary safeguards to thwart unauthorized access, tampering, or manipulation of voting data. This proactive stance on security fortifies the sanctity of the electoral process and upholds democratic tenets of fairness and impartiality [26]. These graphs indicate the superiority of the TAS software as compared to manual testing with considered savings in testing time.

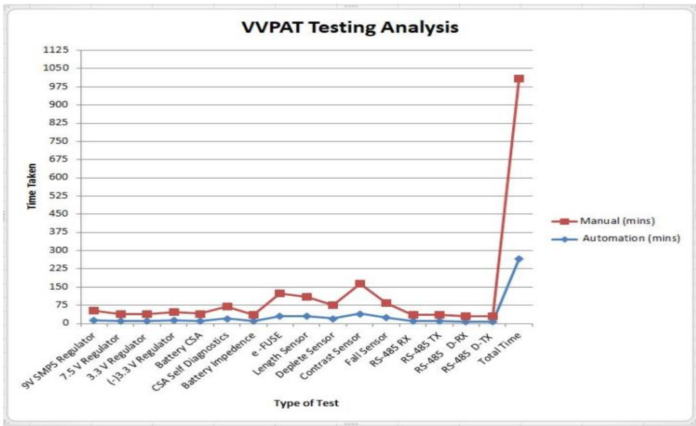

Figure 7. Comparison of automation and manual testing for VVPAT

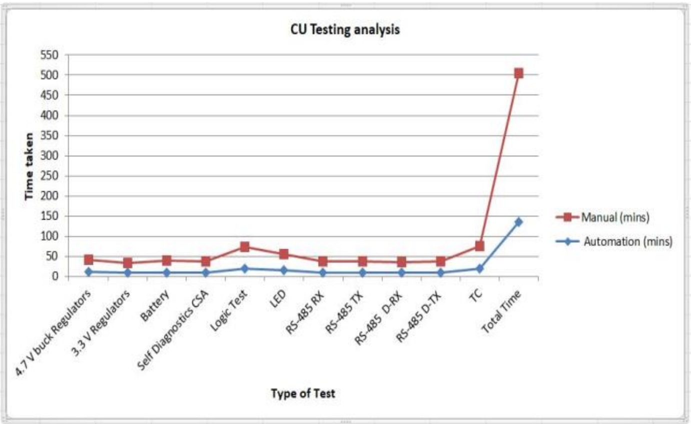

Figure 8. Comparison of automation and manual testing for CU

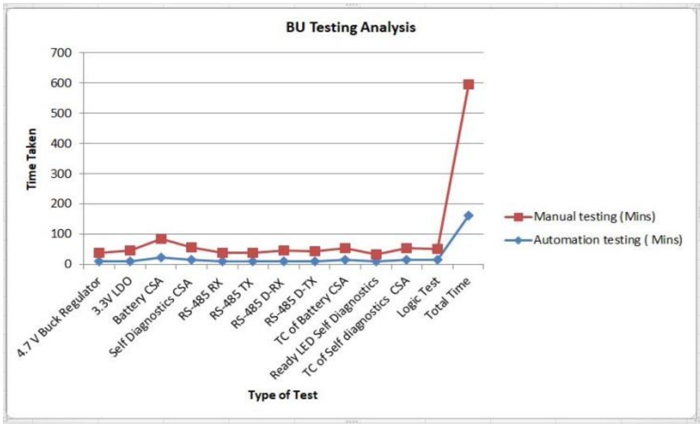

Figure 9. Comparison of automation and manual testing for BU

The time taken by the TAS system for three chosen projects such as CU, BU, and VVPAT is shown in Table 3. It validates the efficacy of the proposed TAS system against the manual testing system. According to this table, the TAS system has saved more than 60% of the time when compared to the manual testing method.

Table 3. Experimental results of improvement in time by using automated testing software

Project	Total no of tests	Manual testing time	Automation testing time	Savings in time (%)
CU	54	370 min 35 sec	135 min 05 sec	63.51
BU	51	433 min 45 sec	162 min 22 sec	62.58
VVPAT	205	744 min 30 sec	266 min 37 sec	64.25

5. CONCLUSION

The industrial revolution in manufacturing, like Industry 4.0, requires a suitable technique and solution for the automation of test and measurement systems which are commonly performed using a DO. This work carries out a case study to validate the efficacy of the ATE with automated ETAS.EXE software by operating the DO using VB.NET. Three different projects, such as CU, BU, and VVPAT, have been considered for such purposes to facilitate the automated testing of PCBAs. A total of 54, 51, and 205 manual and ATE tests have been conducted for the CU, BU, and VVPAT projects, respectively, to observe the savings in testing time. Results of this work reveal a significant amount of time savings (approximately 60%) using the ATE system as compared to manual testing. Furthermore, the developed software allows remote control of the oscilloscope. The make in India initiative and other global factors are very much in favour of such development in the field of electronic and semiconductor manufacturing industries. The use of automated software tools for PCBAs and components will exponentially increase in the future to run the system at maximum capacity. Many oscilloscopes offer a balance between performance and simplicity by providing the user with many ways to operate the instrument. Nevertheless, the use of automated TM systems will enhance productivity by saving time, human error, and labour. Further, it can reduce human fatigue, and stress, thus assisting in human resource management. The advancement of recent technologies such as machine learning, the IoT, robotics, artificial intelligence, 5G services will make remote operations easier. The application of these technologies will expand the capabilities of ATE DO in mass TM of PCBAs in the electronics manufacturing industry, both economically and effectively.

REFERENCES

[1] M. B. Nagapure and R. M. Deshmukh, "PLC based Segregation of Scrap Material," *International Journal of Engineering Research and Applications*, vol. 07, no. 04, pp. 6–10, Apr. 2017, doi: 10.9790/9622-0704030610.

[2] C. J. Bartodziej, "The Concept Industry 4.0 - An Empirical Analysis of Technologies and Applications in Production Logistics," *Springer Fachmedien Wiesbaden GmbH*, 2017.

[3] B. A. Kadir, "Designing new ways of working in Industry 4.0: Aligning humans, technology, and organization in the transition to Industry 4.0," 2020.

[4] C. D. Kuenzi and C. D. Ziomek, "Fundamentals of oscilloscope measurements in automated test equipment (ATE)," in *AUTOTESTCON (Proceedings)*, Sep. 2006, pp. 244–252. doi: 10.1109/AUTEST.2006.283645.

[5] A. Rojko, "Industry 4.0 concept: Background and overview," *International Journal of Interactive Mobile Technologies*, vol. 11, no. 5, pp. 77–90, Jul. 2017, doi: 10.3991/ijim.v11i5.7072.

[6] S. Shmakov, M. Cherniak, A. Boruzdina, P. Skorobogatov, and A. Nikiforov, "Automated Data Processing System for Oscilloscope Measurements during an Environmental Test," in *MATEC Web of Conferences*, 2016, vol. 79. doi: 10.1051/matecconf/20167901068.

[7] M. Huang, W. Liu, T. Wang, H. Song, X. Li, and A. Liu, "A queuing delay utilization scheme for on-path service aggregation in services-oriented computing networks," *IEEE Access*, vol. 7, pp. 23816–23833, 2019, doi: 10.1109/ACCESS.2019.2899402.

[8] A. D. Dwivedi, G. Srivastava, S. Dhar, and R. Singh, "A decentralized privacy-preserving healthcare blockchain for IoT," *Sensors*, vol. 19, no. 2, pp. 1–17, Jan. 2019, doi: 10.3390/s19020326.

[9] F. Al-Turjman, H. Zahmatkesh, and L. Mostarda, "Quantifying uncertainty in internet of medical things and big-data services using intelligence and deep learning," *IEEE Access*, vol. 7, pp. 115749–115759, 2019, doi: 10.1109/ACCESS.2019.2931637.

[10] S. Kumar and M. Singh, "Big data analytics for healthcare industry: Impact, applications, and tools," *Big Data Mining and Analytics*, vol. 2, no. 1, pp. 48–57, Mar. 2019, doi: 10.26599/BDMA.2018.9020031.

[11] N. Stylos and J. Zwiegelaar, "Big data as a game changer: How does it shape business intelligence within a tourism and hospitality industry context?," *Big Data and Innovation in Tourism, Travel, and Hospitality: Managerial Approaches, Techniques, and Applications*, pp. 163–181, 2019, doi: 10.1007/978-981-13-6339-9_11.

[12] L. M. Ang, K. P. Seng, G. K. Ijemaru, and A. M. Zungeru, "Deployment of IoV for Smart Cities: Applications, Architecture, and Challenges," *IEEE Access*, vol. 7, pp. 6473–6492, 2019, doi: 10.1109/ACCESS.2018.2887076.

[13] B. P. L. Lau *et al.*, "A survey of data fusion in smart city applications," *Information Fusion*, vol. 52, pp. 357–374, Dec. 2019, doi: 10.1016/j.inffus.2019.05.004.

[14] Y. Wu *et al.*, "Large scale incremental learning," in *Proceedings of the IEEE Computer Society Conference on Computer Vision and Pattern Recognition*, Jun. 2019, vol. 2019-June, pp. 374–382. doi: 10.1109/CVPR.2019.00046.

[15] Q. Song, H. Ge, J. Caverlee, and X. Hu, "Tensor completion algorithms in big data analytics," *ACM Transactions on Knowledge*

Discovery from Data, vol. 13, no. 1, pp. 1–48, Feb. 2019, doi: 10.1145/3278607.
[16] A. Saikia, S. Joy, D. Dolma, and R. Mary. R, “Comparative performance analysis of MySQL and SQL server relational database management systems in windows environment,” *International Journal of Advanced Research in Computer and Communication Engineering*, vol. 4, no. 3, pp. 160–164, 2015, doi: 10.17148/ijarcce.2015.4339.
[17] A. Mosavi, S. Shamshirband, E. Salwana, K. wing Chau, and J. H. M. Tah, “Prediction of multi-inputs bubble column reactor using a novel hybrid model of computational fluid dynamics and machine learning,” *Engineering Applications of Computational Fluid Mechanics*, vol. 13, no. 1, pp. 482–492, Jan. 2019, doi: 10.1080/19942060.2019.1613448.
[18] V. Palanisamy and R. Thirunavukarasu, “Implications of big data analytics in developing healthcare frameworks – A review,” *Journal of King Saud University - Computer and Information Sciences*, vol. 31, no. 4, pp. 415–425, Oct. 2019, doi: 10.1016/j.jksuci.2017.12.007.
[19] J. Sadowski, “When data is capital: Datafication, accumulation, and extraction,” *Big Data and Society*, vol. 6, no. 1, pp. 1–12, Jan. 2019, doi: 10.1177/2053951718820549.
[20] J. R. Saura, B. R. Herraez, and A. Reyes-Menendez, “Comparing a traditional approach for financial brand communication analysis with a big data analytics technique,” *IEEE Access*, vol. 7, pp. 37100–37108, 2019, doi: 10.1109/ACCESS.2019.2905301.
[21] D. Nallaperuma *et al.*, “Online Incremental Machine Learning Platform for Big Data-Driven Smart Traffic Management,” *IEEE Transactions on Intelligent Transportation Systems*, vol. 20, no. 12, pp. 4679–4690, Dec. 2019, doi: 10.1109/TITS.2019.2924883.
[22] S. Schulz, M. Becker, M. R. Groseclose, S. Schadt, and C. Hopf, “Advanced MALDI mass spectrometry imaging in pharmaceutical research and drug development,” *Current Opinion in Biotechnology*, vol. 55, pp. 51–59, Feb. 2019, doi: 10.1016/j.copbio.2018.08.003.
[23] C. Shang and F. You, “Data Analytics and Machine Learning for Smart Process Manufacturing: Recent Advances and Perspectives in the Big Data Era,” *Engineering*, vol. 5, no. 6, pp. 1010–1016, Dec. 2019, doi: 10.1016/j.eng.2019.01.019.
[24] M. Aqib, R. Mehmood, A. Alzahrani, I. Katib, A. Albeshri, and S. M. Altowaijri, “Smarter traffic prediction using big data, in-memory computing, deep learning and gpus,” *Sensors*, vol. 19, no. 9, pp. 2206–2239, May 2019, doi: 10.3390/s19092206.
[25] Y. Yu, M. Li, L. Liu, Y. Li, and J. Wang, “Clinical big data and deep learning: Applications, challenges, and future outlooks,” *Big Data Mining and Analytics*, vol. 2, no. 4, pp. 288–305, Dec. 2019, doi: 10.26599/BDMA.2019.9020007.
[26] G. Xu, Y. Shi, X. Sun, and W. Shen, “Internet of things in marine environment monitoring: A review,” *Sensors (Switzerland)*, vol. 19, no. 7, pp. 1–21, Apr. 2019, doi: 10.3390/s19071711.

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