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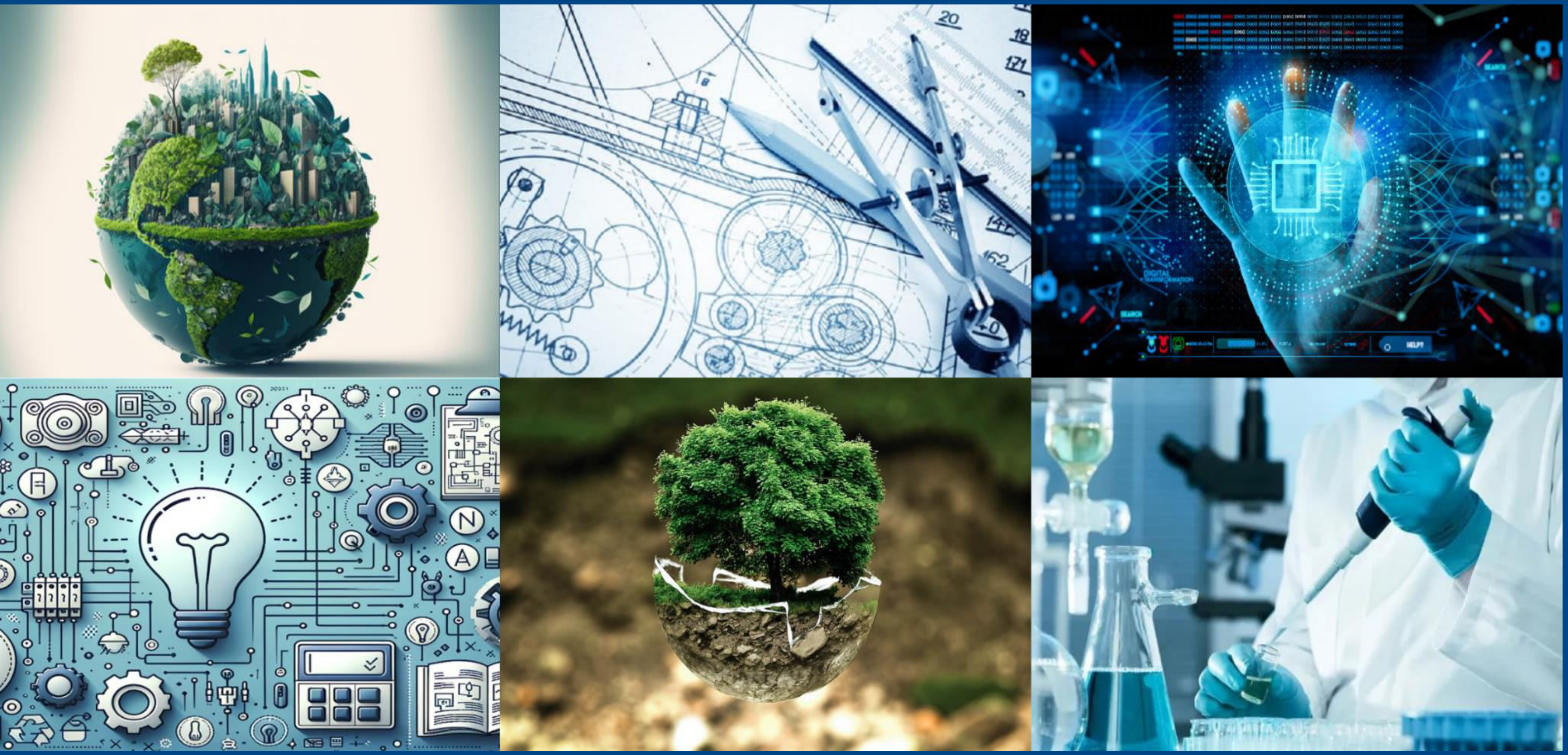

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www.ijmrset.com ijmrset@gmail.com +91 6381 907 438 +91 63819 07438

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Design and Development of SeismoBuddy: A Mobile Companion Robot for Abnormal Shake Detection and Post-Event Vibration Assessment

Archelle Eman E. Samontina, Engr. Cheryl O. Tayo, Engr. Franklin M. Ganancias,

Engr. Nelyne Lourdes Y. Plaza, Engr. Dione S. Duero, Benedict P. Comon, and Christian B. Suarez

Undergraduate Student, Department of Computer Studies, North Eastern Mindanao State University - Cantilan Campus, Cantilan, Surigao del Sur, Philippines

Email: ebol.archelle@gmail.com

ABSTRACT: Earthquakes remain a constant threat in the Philippines, especially in regions such as Caraga where household-level disaster awareness is still limited despite existing national monitoring systems. This study presents SeismoBuddy, a mobile companion robot designed to support abnormal shake detection and post-earthquake vibration assessment in earthquake-prone communities. The device uses an MPU6050 accelerometer for shake detection, a fifteen-second post-event vibration assessment routine, animated facial expressions displayed on an SSD1306 OLED, autonomous movement using two N20 gear motors, touch-based interaction, and a local WiFi captive portal hosted on a Seeed XIAO ESP32-C3 microcontroller. The system applies a dynamic threshold algorithm with a 1.5 g trigger and classifies vibrations as either ACTIVE or SETTLING based on activity detected during a fifteen-second analysis period. Testing showed one hundred percent specificity against incidental movement and one hundred percent sensitivity for strong shakes above the threshold. A Likert-scale evaluation involving fifty (50) respondents produced an overall weighted mean of 4.15, interpreted as Agree, while Usability and Acceptability received Strongly Agree ratings. The findings indicate that SeismoBuddy is a functional and user-friendly companion robot that can help improve household-level seismic awareness in earthquake-prone areas of the Philippines.

KEYWORDS: Abnormal Shake Detection, Companion Robot, ESP32-C3, MPU6050 Accelerometer, Captive Portal, Embedded Systems, Disaster Awareness, Philippines

I. INTRODUCTION

Earthquakes are among the most destructive natural hazards in the world, particularly in countries situated along major tectonic boundaries. The United Nations Office for Disaster Risk Reduction (UNDRR, 2025) [1] reports that earthquakes consistently rank among the leading causes of casualties and economic loss globally. The Philippines sits within that high-risk zone, positioned along the Pacific Ring of Fire, where thousands of seismic events are recorded yearly with major destructive quakes tied to the Philippine Fault Zone, the Manila Trench, and the Philippine Trench (PHIVOLCS, 2025) [2]. Surigao del Sur and the rest of Caraga have felt this directly, with magnitude 7.4 earthquakes offshore Hinatuan in December 2023 and offshore Davao Oriental in October 2025, the latter producing 299 aftershocks within hours of the mainshock (Aurelio and Catugas, 2024) [3].

Despite ongoing improvements in the Philippine Seismic Network, several studies have flagged a persistent problem: households remain under-prepared. Evasco et al. (2022) [4] found that practical readiness inside the home is often thin even when general awareness exists. Bollettino et al. (2024) [5], in a Harvard Humanitarian Initiative survey of 4,608 Filipinos, reported a national preparedness score of 19.2 out of 50, with the Caraga Region scoring only 18.0 out of 50, almost unchanged from seven years ago. Chong et al. (2025) [6] added that disaster risk perception in the Philippines varies sharply by region and is shaped by socioeconomic gaps. The pattern is consistent: institutional monitoring continues to improve while awareness and response at the household level lag behind, especially in rural areas where dedicated seismic instruments are not part of daily life.

This study addresses that gap by introducing SeismoBuddy, a mobile desk companion robot that detects abnormal shake events and runs a short post-event vibration assessment using a low-cost embedded system. The device pairs an MPU6050 accelerometer with a Seeed XIAO ESP32-C3 microcontroller for shake detection, uses an SSD1306 OLED display with animated facial expressions for user feedback, and hosts a local WiFi captive portal that gives the user smartphone-accessible control even when external networks are unavailable. The aim is to contribute a practical, household-level reference for how embedded systems can support disaster awareness in earthquake-prone regions of the Philippines, starting from Surigao del Sur.

II. LITERATURE REVIEW

A critical review of related studies was conducted to establish the relationship between the present study and previous research on low-cost embedded seismic detection systems, decentralised earthquake early warning networks, companion robotics, and Philippine household-level disaster preparedness.

Gunoro et al. (2023) [7] presented an Internet of Things based earthquake warning alarm using an accelerometer sensor, demonstrating that household-deployable shake detectors are feasible at minimal cost. Their prototype reliably triggered alerts when acceleration thresholds were exceeded, supporting the technical foundation for low-cost embedded shake detection.

Bassetti and Panizzi (2022) [8] proposed an edge-based earthquake detection network where Raspberry Pi and NodeMCU devices handle processing locally and tolerate partial network disruption. Their work demonstrated the value of distributed and offline-capable architectures in seismic applications, especially in disaster-prone regions where internet infrastructure may fail.

Prasanna et al. (2022) [9] showed that a decentralised earthquake early warning architecture built around MEMS-based accelerometers hosted by general members of the public can reduce warning latency compared with traditional centralised cloud-based systems. Paul et al. (2023) [10] reported similar findings using low-cost, citizen-hosted Raspberry Shake seismometers in Haiti, confirming that consumer-grade devices can play a meaningful role in seismic monitoring within resource-constrained contexts.

Kadylak et al. (2021) [11] and Hofstede et al. (2025) [12] argued that social and assistive domestic robots show strong potential for supporting independence and engagement when their design is approachable. Park and Williams (2025) [13] reported that older adults responded more positively to robots that expressed emotions naturally and adapted their interactions, supporting the value of expressiveness in companion robot design.

Within the Philippines, Evasco et al. (2022) [4] and Vinck/Bollettino et al. (2024) [5] documented persistent gaps in household-level earthquake preparedness. The Cooperative Development Authority Caraga (2024) [14] emphasized that locally appropriate, affordable disaster-readiness tools remain a regional priority. These works collectively justify the development of accessible, household-facing seismic awareness tools tailored to the Filipino context.

Table 1. Summary of Relevant Literature

No.	Paper Title	Author(s)	Key Points	Remark
1	Design of Earthquake Warning Alarm Using Accelerometer Sensor Based on IoT	Gunoro et al. (2023)	Developed an IoT-based earthquake warning alarm using an accelerometer sensor	Demonstrated feasibility of household-deployable shake detectors at low cost
2	Earthquake Detection at the Edge: IoT Crowdsensing Network	Bassetti and Panizzi (2022)	Proposed an edge-based earthquake detection network using Raspberry Pi and NodeMCU	Showed the value of distributed and offline-capable architectures for disaster monitoring

3	Decentralized Earthquake Early Warning Systems	Prasanna et al. (2022)	Built a decentralised early warning architecture using publicly hosted MEMS sensors	Provided basis for low-latency, citizen-hosted seismic monitoring networks
4	Huggable Integrated Socially Assistive Robots	Hofstede et al. (2025)	Introduced the HI-SAR concept combining huggable form with assistive functionality	Supported the companion-robot design framing adopted in SeismoBuddy
5	Earthquake Awareness and Preparedness Among the Public in the Philippines	Evasco et al. (2022)	Documented thin household-level practical readiness despite general awareness	Established the local disaster preparedness gap addressed in this study

In summary, previous studies demonstrated the effectiveness of low-cost MEMS sensors and microcontrollers in seismic detection, the feasibility of decentralised citizen-hosted seismic networks, and the value of companion-robot design in everyday adoption. However, limited studies have focused on integrating these technologies into a localized, household-level companion robot specifically designed for Filipino communities. This study addresses these gaps by combining MEMS-based shake detection, post-event vibration assessment, captive portal control, and animated companion-robot interaction into a single integrated system.

III. METHODOLOGY

Research Design

The study utilized a developmental research design to design, build, integrate, and evaluate SeismoBuddy, a mobile companion robot for household-level abnormal shake detection and post-event vibration assessment in earthquake-prone communities. The development followed an iterative approach based on the Agile methodology, where features were built, tested, and refined in repeated cycles until the system achieved acceptable functionality, reliability, accuracy, and usability.

Research Respondents

The respondents of the study consisted of fifty (50) individuals selected through convenience sampling. The group was composed of thirty (30) students from NEMSU – Cantilan Campus, ten (10) instructors from NEMSU, and ten (10) working students residing in the locality. The respondent composition ensured diverse perspectives on system functionality, reliability, usability, user experience, and acceptability.

Research Instrument

The study used a structured Likert-scale questionnaire developed by the researchers as the primary evaluation instrument. The questionnaire contained thirty-five (35) evaluation items distributed across seven assessment criteria: functionality, reliability, accuracy, efficiency, usability, user experience, and acceptability. Each criterion was represented by five evaluation statements rated on a five-point Likert scale, ranging from Strongly Agree (5) to Strongly Disagree (1).

Data Gathering Procedure

Data gathering started with controlled testing of the SeismoBuddy prototype to verify shake detection consistency at the 1.5 g threshold, post-event vibration classification reliability across repeated trials, captive portal control responsiveness during smartphone-based interaction, and battery operation duration under continuous use. Respondents then interacted with the prototype in a controlled setting, after which they completed the structured Likert-scale questionnaire based on their experience. The researchers also conducted brief informal interviews to capture qualitative observations about the device's appearance, expressiveness, and perceived usefulness.

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Data Analysis

The quantitative and technical data gathered from system testing and respondent evaluation were analyzed using the following statistical and performance metrics:

Weighted mean was used to determine the average evaluation score for each of the seven assessment criteria based on respondent responses, using the formula $WM = \Sigma fX / N$, where f is the frequency of responses, X is the scale value, and N is the total number of respondents.

Verbal interpretation was applied to the computed weighted means using a qualitative scale: 1.0–1.8 (Strongly Disagree), 1.9–2.6 (Disagree), 2.7–3.4 (Neutral), 3.5–4.2 (Agree), and 4.3–5.0 (Strongly Agree).

Sensitivity was measured by computing the percentage of trials in which an actual abnormal shake event correctly triggered the detection algorithm, using the formula: Sensitivity = (True Positives ÷ Total Actual Shakes) × 100%.

Specificity was measured by computing the percentage of trials in which non-event motion (light desk taps) correctly did not trigger the detection algorithm, using the formula: Specificity = (True Negatives ÷ Total Non-event Trials) × 100%.

Active sample ratio was computed during the post-event vibration assessment to classify vibration as ACTIVE or SETTLING, calculated as the proportion of samples within the fifteen-second analysis window where dynamic g exceeded the secondary 0.3 g threshold.

Response time analysis was conducted to evaluate the captive portal control panel responsiveness, measured as the average elapsed time in seconds between user command input and system response.

IV. RESULTS AND DISCUSSION

System Performance Evaluation

The developed SeismoBuddy system demonstrated reliable performance in detecting and classifying abnormal shake events under controlled conditions. The system achieved one hundred percent specificity against incidental motion (zero false triggers across ten light-tap trials) and one hundred percent sensitivity for strong shakes clearly above the 1.5 g threshold (ten triggers across ten trials). Moderate shakes near the threshold boundary produced borderline behavior with forty percent sensitivity, reflecting the expected tradeoff between sensitivity and false-alarm rejection that informed the design of the threshold value.

The post-event vibration assessment routine produced consistent classifications across test conditions. Brief decaying motion was correctly labeled as SETTLING (active sample ratio of 0.04), continuous shaking as ACTIVE (active sample ratio of 0.27), and repeated bursts as ACTIVE (active sample ratio of 0.13). The captive portal control panel responded to user commands within an average of three to five seconds, and the device supported approximately six hours of continuous active operation, twelve hours of idle operation, and up to twenty hours in low-activity modes on a single charge of the 2000mAh lithium-polymer battery.

Functionality Evaluation

Table 2. Functionality Evaluation

Evaluation Criteria	Mean	Interpretation
Functionality	4.12	Agree

The functionality evaluation confirmed that SeismoBuddy effectively detects abnormal shake events, runs the post-event vibration assessment, displays clear visual indicators through animated OLED expressions and on-screen messages, and operates autonomously across the desk surface. Respondents found the system functional as a desk companion safety device with a weighted mean of 4.12, interpreted as Agree.

Reliability Evaluation

Table 3. Reliability Evaluation

Evaluation Criteria	Mean	Interpretation
Reliability	3.91	Agree

The reliability evaluation showed that SeismoBuddy operates consistently without malfunction during normal use and maintains stable performance during repeated shake-detection tests. With a weighted mean of 3.91, interpreted as Agree, this was the lowest-rated criterion, primarily due to the lower scores on extended battery operation (3.62), which the researchers acknowledge as an honest area for future improvement.

Accuracy Evaluation

Table 4. Accuracy Evaluation

Evaluation Criteria	Mean	Interpretation
Accuracy	4.15	Agree

The accuracy evaluation demonstrated that SeismoBuddy correctly detects shake events at the configured sensitivity threshold, accurately classifies post-event vibration as either active or settling, and minimizes false alarms during normal desk activity. Respondents rated the system's accuracy with a weighted mean of 4.15, interpreted as Agree.

Efficiency Evaluation

Table 5. Efficiency Evaluation

Evaluation Criteria	Mean	Interpretation
Efficiency	4.08	Agree

The efficiency evaluation confirmed that SeismoBuddy responds quickly to abnormal shake events, completes the post-event vibration assessment within a reasonable time, and supports responsive captive portal control. The system received a weighted mean of 4.08 on efficiency, interpreted as Agree.

Usability Evaluation

Table 6. Usability Evaluation

Evaluation Criteria	Mean	Interpretation
Usability	4.32	Strongly Agree

The usability evaluation showed that SeismoBuddy is easy to understand and operate, with a user-friendly captive portal control panel and clearly interpretable OLED expressions. Respondents found the system suitable for household use, including homes, classrooms, and small offices. With a weighted mean of 4.32, interpreted as Strongly Agree, usability was one of the highest-rated criteria.

User Experience Evaluation

Table 7. User Experience Evaluation

Evaluation Criteria	Mean	Interpretation
User Experience	4.15	Agree

The user experience evaluation confirmed that the animated facial expressions are pleasant and emotionally legible, the touch-based petting interaction adds to the enjoyment of using the device, and the robot behaves like a helpful and approachable companion. Respondents rated user experience with a weighted mean of 4.15, interpreted as Agree.

Acceptability Evaluation

Table 8. Acceptability Evaluation

Evaluation Criteria	Mean	Interpretation
Acceptability	4.35	Strongly Agree

The acceptability evaluation produced the highest weighted mean among all seven criteria at 4.35, interpreted as Strongly Agree. Respondents reported that SeismoBuddy is helpful in promoting awareness during seismic events at the desk level, that having the device in their home, classroom, or workspace would be beneficial, and that they would recommend the system to others living or working in earthquake-prone areas. The single highest-rated item was on the device's value to household-level disaster awareness, with a mean of 4.52.

Overall Evaluation

Across all seven assessment criteria, SeismoBuddy received an overall weighted mean of 4.15, interpreted as Agree. Among the 1,750 individual Likert-scale responses gathered from the fifty respondents (50 respondents × 35 items), 36.17 percent were rated as Strongly Agree and 45.03 percent as Agree, together accounting for 81.20 percent of all responses. This strong concentration of positive responses, paired with very low frequency of negative ratings (1.94 percent Disagree, 0.06 percent Strongly Disagree), supports the interpretation that the SeismoBuddy system was generally well-received by the intended users.

V. CONCLUSION

The development of SeismoBuddy represents a practical contribution to household-level disaster awareness in earthquake-prone regions of the Philippines. The system successfully addressed the limitations of the existing household-level seismic awareness gap by combining low-cost MEMS-based shake detection, structured post-event vibration analysis, animated OLED expressions, autonomous behavior, touch-based interaction, and local captive-portal control within a single low-power embedded device. Testing confirmed that the system operates reliably under controlled conditions with one hundred percent specificity against incidental motion and one hundred percent sensitivity for strong shakes above the threshold, while the structured Likert-scale evaluation with fifty respondents produced an overall weighted mean of 4.15 (Agree), with Usability (4.32) and Acceptability (4.35) reaching the Strongly Agree interpretation.

While limitations remain in battery endurance and the smoothness of autonomous motor movement, both are honestly acknowledged areas for future improvement that may be addressed through battery capacity upgrades, motor calibration improvements, and the introduction of pulse-width modulation control. Future work may also explore threshold calibration using reference data from PHIVOLCS seismic stations, the integration of optional internet-based alerting while preserving offline-first behavior, and broader testing in rural and coastal communities across earthquake-prone provinces. SeismoBuddy serves as an accessible reference design for low-cost embedded systems that contribute to disaster awareness at the household scale and offers Filipino households, schools, and small offices a tangible example of how accessible technology can support continuous seismic awareness.

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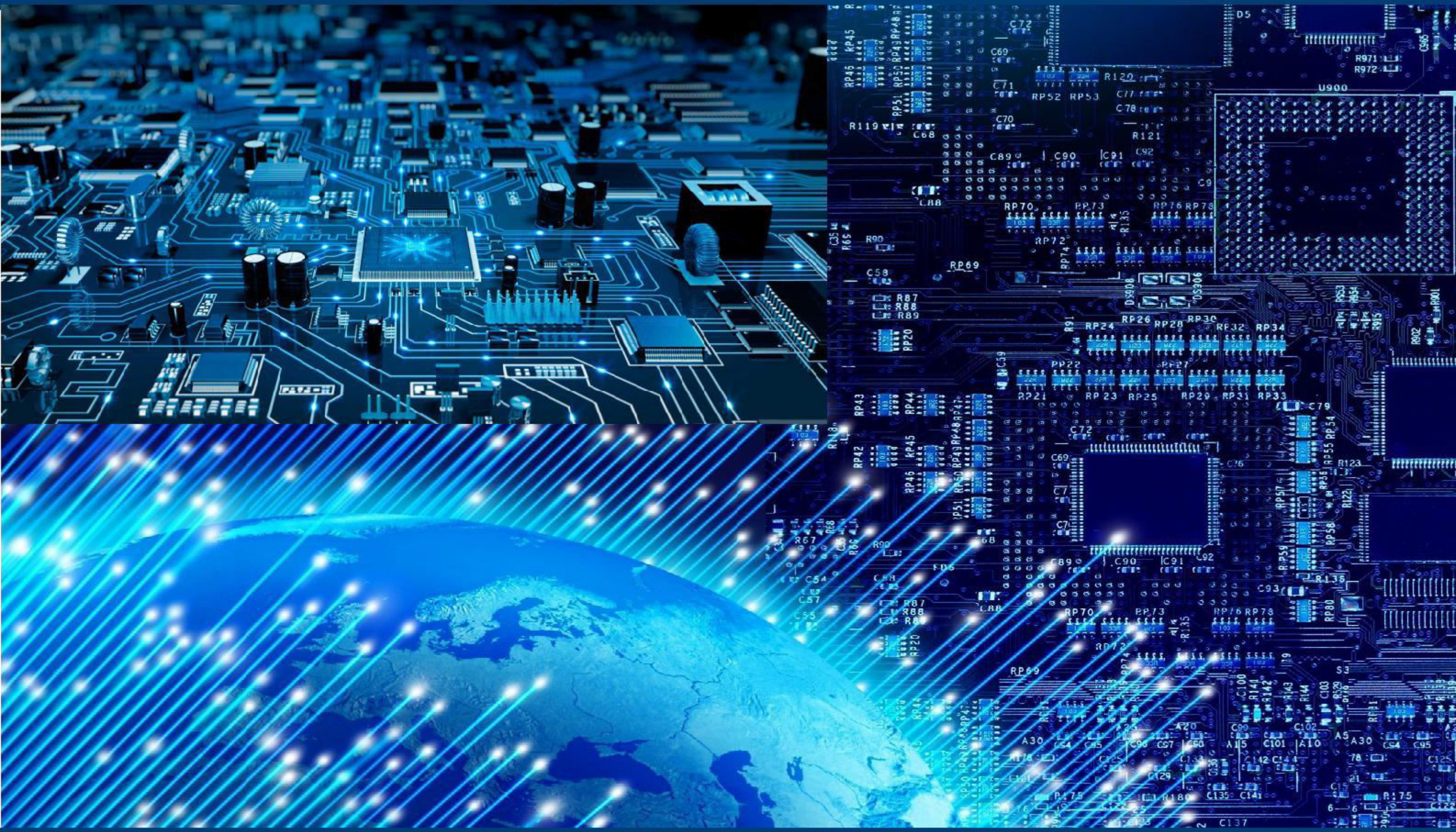

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