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Performance Analysis of the MPU6050 Sensor for Room Inclination Measurement Based on the Internet of Things

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ABSTRACT

Building safety monitoring has grown increasingly dependent on low-cost sensing solutions — and for good reason. Structural tilt, when left undetected, accumulates into deformation patterns that compromise both occupant safety and long-term building integrity. This study developed an IoT-based room inclination monitoring system by pairing an MPU6050 inertial sensor with an ESP32 microcontroller to capture, process, and transmit tilt data across three measurement axes in real time. The system computes pitch and roll angles from raw accelerometer outputs and delivers the results through a web-based interface, allowing users to record wall and floor orientations independently before calculating the combined inclination angle via the dot product method. Ten repeated trials were conducted against a calibrated 90° wall-to-floor reference angle to assess system reliability. The mean recorded angle was 88.06°, reflecting a deviation of 1.94° from the reference — a gap narrow enough to confirm basic functional validity, yet wide enough to warrant concern in precision-critical contexts. All measured values fell consistently below the 90° threshold, suggesting a systematic offset rather than random error. The absence of digital filtration — no Kalman or Complementary filter was applied to the raw data — appears to be the primary contributor to this pattern, compounded by minor sensor placement inconsistencies during testing. Future work must address calibration offset correction and signal noise attenuation before the system can be considered adequate for structural health monitoring or smart building applications.

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Internet of Things; MPU6050 Sensor; ESP32 Microcontroller; Structural Safety; Room Inclination Monitoring.

ABSTRAK

Pemantauan keamanan bangunan kini semakin bergantung pada solusi penginderaan berbiaya rendah — dan alasannya cukup mendasar. Kemiringan struktural yang tidak terdeteksi secara bertahap berkembang menjadi pola deformasi yang mengancam keselamatan penghuni sekaligus integritas bangunan dalam jangka panjang. Penelitian ini mengembangkan sistem pemantauan kemiringan ruangan berbasis IoT dengan memadukan sensor inersia MPU6050 dan mikrokontroler ESP32 untuk menangkap, memproses, serta mengirimkan data kemiringan pada tiga sumbu pengukuran secara *real-time*. Sistem menghitung sudut *pitch* dan *roll* dari keluaran akselerometer mentah dan menyajikan hasilnya melalui antarmuka berbasis web, memungkinkan pengguna merekam orientasi dinding dan lantai secara terpisah sebelum menghitung sudut kemiringan gabungan menggunakan metode *dot product*. Sepuluh percobaan berulang dilakukan terhadap sudut referensi 90° yang telah dikalibrasi antara dinding dan lantai guna menilai keandalan sistem. Rata-rata sudut yang tercatat adalah 88,06°, mencerminkan deviasi sebesar 1,94° dari referensi — selisih yang cukup kecil untuk mengonfirmasi validitas fungsional dasar, namun cukup besar untuk menimbulkan kekhawatiran dalam konteks yang menuntut presisi tinggi. Seluruh nilai terukur secara konsisten berada di bawah ambang 90°, mengindikasikan adanya *offset* sistematis, bukan sekadar kesalahan acak. Ketiadaan filtrasi digital — tidak ada filter Kalman maupun *Complementary filter* yang diterapkan pada data mentah — tampaknya menjadi kontributor utama pola ini, diperparah oleh ketidakkonsistenan penempatan sensor selama pengujian. Penelitian selanjutnya perlu menangani koreksi *offset* kalibrasi dan reduksi *noise* sinyal sebelum sistem ini dapat dianggap memadai untuk pemantauan kesehatan struktural atau aplikasi bangunan cerdas.

KATA KUNCI
Internet of Things; Sensor MPU6050; Mikrokontroler ESP32; Keamanan Struktural; Pemantauan Kemiringan Ruangan.

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1. Introduction

Monitoring building movement is one of the more direct ways to preserve structural safety, particularly in areas prone to seismic activity, land subsidence, or variable loading conditions. Minor displacements, when left unchecked, accumulate — and what begins as a hairline deviation can eventually manifest as permanent deformation, reduced load-bearing capacity, and, in worst cases, structural collapse (Albani Musyafa', 2023; Selly Novota Sari *et al*., 2025). Advances in sensing technology — strain gauges, accelerometers, and their derivatives — have made it increasingly practical to embed monitoring capability directly into IoT frameworks and wireless communication systems, enabling continuous, low-power data acquisition without the constraints of wired infrastructure (Eric, 2025).

Residential structures represent one of the most persistent demands in built environments. Every dwelling depends on a floor as a foundational structural plane, yet floors are rarely treated as the load-bearing, stability-critical elements they actually are (Aprilia Putri Anggraeni *et al*., 2025). Structural tilt — when it occurs — carries diagnostic value: rotational angles in horizontal members and lateral drift in vertical ones together describe the deformation state of a building in ways that static visual inspection simply cannot. The MPU6050 addresses this measurement need through three integrated sensing components — a gyroscope, an accelerometer, and a temperature sensor — a combination that makes it adaptable across a wide range of orientation-sensing applications (Muhammad Fathur Rahman N *et al*., 2022). Inclinometers built around such sensors are now routinely used to assess structural deformation through rotational measurement, with tilt data functioning as a primary indicator of component-level and system-level safety (Dae Woong Ha *et al*., 2013).

From this basis, a monitoring system was developed to detect structural inclination in buildings resulting from internal strain. The system is intended to give building managers early, actionable information — not merely a record of what has already failed, but a signal that something is changing. Real-time monitoring through internet-connected devices makes this possible (Muhammad Asri *et al*., 2021). Social networks, distributed systems, and real-time architectures — the core constituents of IoT — are being deployed with increasing frequency in structural monitoring contexts (Zambrano *et al*., 2017; Washilla Audia *et al*., 2025). Room inclination, in this regard, is not a peripheral concern. It affects building safety assessments, equipment placement, and basic spatial comfort — and measuring it accurately requires integrating data from both wall and floor planes, rather than treating either surface in isolation. An approach that combines information from both reference planes enables a more accurate and representative determination of the actual intersection angles within an enclosed space.

2. Methodology

The research adopts a quantitative applied experimental approach covering the design, implementation, and evaluation of an IoT-based inclination monitoring system that uses inertial sensors to capture angular orientation in real time. One challenge inherent to this approach is that attitude estimation — derived independently of prior measurement values — is susceptible to drift, which requires continuous correction to maintain accuracy over time (Hendri Maja Saputra *et al*., 2013). The system comprises several integrated components designed to support data acquisition and processing. The MPU6050 serves as the primary sensing unit, detecting inclination and motion through three-axis accelerometer and gyroscope data. The ESP32 functions as the main microcontroller, handling sensor output processing, programmed logic execution, and wireless data communication. Jumper cables interconnect the components, maintaining stable electrical continuity between the MPU6050 and the ESP32 throughout the testing process.

The research workflow begins with device initialization — establishing a wireless network connection and activating the sensors — and ends with the calculation of the combined inclination angle between wall and floor. Acceleration data along the x-, y-, and z-axes are acquired, normalized, and used to compute pitch and roll angles. These angular values are transmitted to a web server in JSON format and rendered through a real-time interface. Users can store wall and floor orientation data independently using dedicated control buttons. Once both datasets are recorded, the system calculates the combined inclination angle using the dot product method applied to gravitational vectors. The final output — the room inclination angle alongside a visual representation of right-angle geometry — is then displayed on the web page.

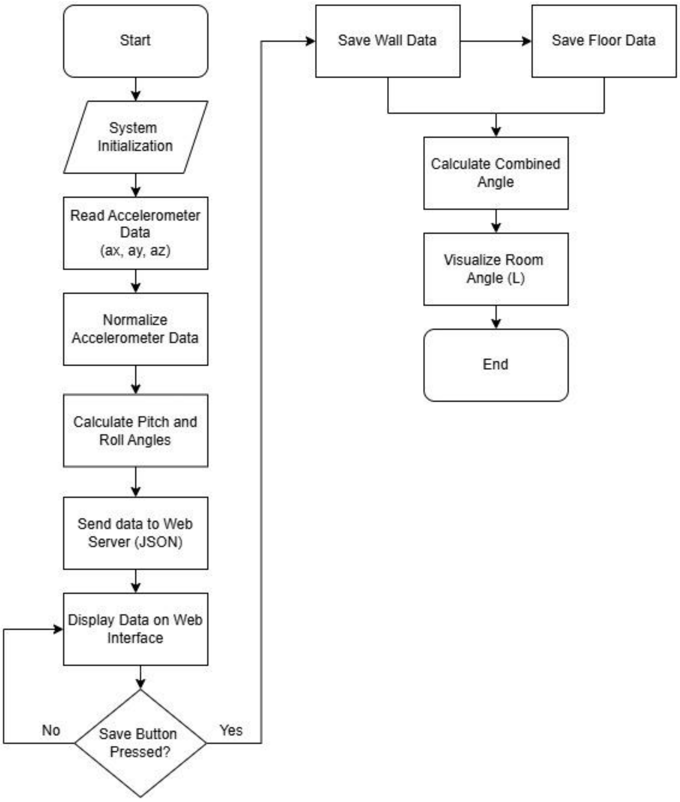


Figure 1. Flowchart of the Accelerometer Data Processing and Room Angle Visualization System

The hardware implementation pairs an ESP32 Dev-Kit V1 microcontroller with an MPU6050 accelerometer and gyroscope sensor. The overall system architecture is illustrated in Figure 2.

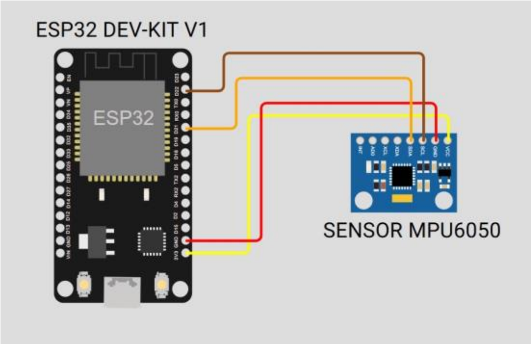


Figure 2. Hardware Interfacing Diagram of ESP32 Dev-Kit V1 and MPU6050 Sensor

Figure 2 illustrates the hardware interfacing diagram between the ESP32 Dev-Kit V1 and the MPU6050 sensor. The two components are connected via the I²C communication protocol, utilizing the dedicated SDA and SCL lines available on the ESP32. Power is supplied to the MPU6050 through the 3.3V pin of the ESP32, while a common ground connection ensures stable electrical reference between both devices. The detailed pin-to-pin wiring configuration is presented in Table 1.

Table 1. Wiring Configuration Between Microcontroller and Inertial Sensor

ESP32 Pin	Sensor Pin	Signal Type
3.3 V	VCC	Power
GND	GND	Ground
GPIO 21	SDA	I²C Data
GPIO 22	SCL	I²C Clock

The wiring configuration follows the I²C communication protocol, where GPIO 21 and GPIO 22 on the ESP32 serve as the data and clock lines respectively. This configuration ensures stable bidirectional communication between the microcontroller and the sensor, forming the hardware foundation upon which the entire data acquisition and processing pipeline depends. Together, these components constitute a compact yet functional measurement platform capable of operating continuously under the experimental conditions described in the following section.

3. Results

The IoT system was tested to assess its capacity to detect angular inclination between wall and floor surfaces using the MPU6050 sensor. Testing involved observing the system's response to various physical orientations of the device when placed on different surfaces.

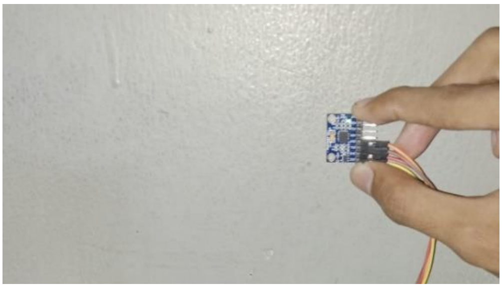
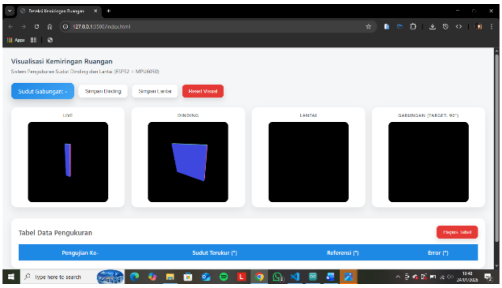


Figure 3. Testing of the MPU6050 Sensor on the wall surface



Visualisasi Kemiringan Ruangan

Sistem Pengukuran Sudut Dinding dan Lantai (ESP32 + MPU6050)

Tabel Data Pengukuran

Pengujian Ke-	Sudut Terukur (°)	Referensi (°)	Error (°)

Figure 4. Website interface display during wall testing

Figure 3 shows the MPU6050 sensor mounted directly on the wall surface. At this stage, the sensor measures wall inclination relative to Earth's gravitational axis, which serves as the primary angular reference. The sensor is secured firmly to the surface to ensure that the acquired acceleration data accurately reflect the actual wall condition. Figure 4 presents the web-based monitoring interface at the moment the *Save Wall* button is activated — the system records the measured wall inclination values and renders them as a three-dimensional visualization, which then serves as the comparative reference for subsequent measurement stages.

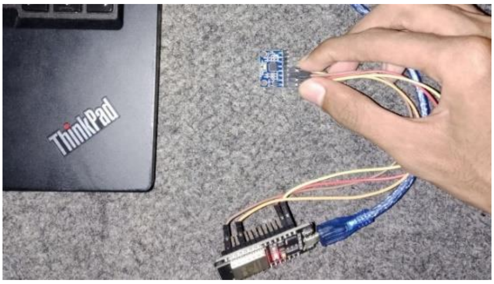
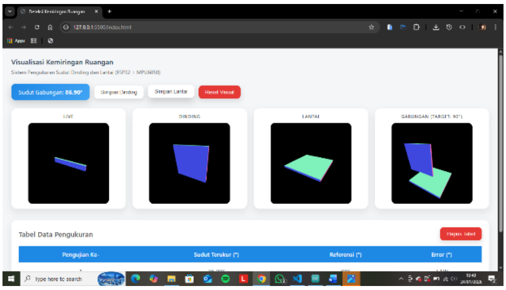


Figure 5. Testing of the MPU6050 sensor on the floor surface



Visualisasi Kemiringan Ruangan

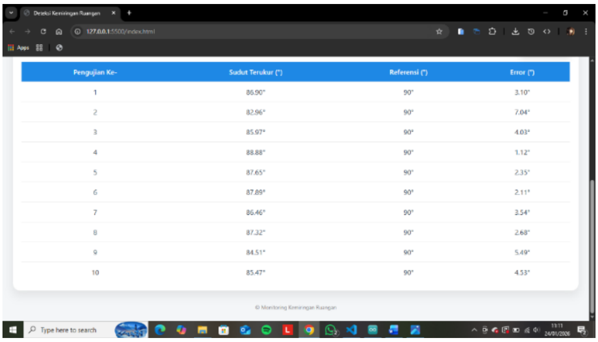
Sistem Pengukuran Sudut Dinding dan Lantai (ESP32 + MPU6050)

Tabel Data Pengukuran

Pengujian Ke-	Sudut Terukur (°)	Referensi (°)	Error (°)

Figure 6. Website interface display during floor testing

Figure 5 depicts the MPU6050 sensor positioned on the floor surface. Here, the sensor measures floor inclination relative to the horizontal plane — the baseline reference for determining the angular difference between floor and wall. Figure 6 presents the monitoring interface during this stage, where the three-dimensional visualization reflects the real-time floor inclination condition as captured by the sensor.



Pengujian Ke-	Sudut Terukur (°)	Referensi (°)	Error (°)
1	86.90°	90°	3.10°
2	82.96°	90°	7.04°
3	85.97°	90°	4.03°
4	88.88°	90°	1.12°
5	87.65°	90°	2.35°
6	87.89°	90°	2.11°
7	86.46°	90°	3.54°
8	87.32°	90°	2.68°
9	84.51°	90°	5.49°
10	85.47°	90°	4.53°

© Monitoring Kemiringan Ruangan

Figure 7. Accuracy test results for right-angle measurements against a 90° reference, presenting measured angles and error values across 10 experimental trials.

System precision and stability were assessed through ten iterative experiments using a calibrated 90° reference angle. Measured values ranged from a minimum of 82.96° to a maximum of 88.88°. Error analysis revealed a fluctuating deviation across trials: the lowest absolute error was 1.12° (Trial 4), while the highest reached 7.04° (Trial 2). Across all ten trials, the mean error was approximately 3.60°. These figures confirm that the ESP32–MPU6050 configuration communicates and visualizes data in real time — but raw accelerometer readings carry variance that undermines high-precision consistency. That gap between functional operation and measurement reliability is, frankly, the more important finding here. What the error distribution reveals is arguably more telling than the mean alone. All recorded values fell consistently below the 90° target, suggesting a systematic offset rather than random scatter. Several factors likely account for this pattern: the inherent sensitivity of MEMS accelerometers to mechanical vibrations, the absence of advanced filtration algorithms — Kalman or Complementary filters, for instance — in the raw data processing stage, and minor physical misalignments during sensor placement or surface irregularities on the measured wall. Addressing this in future iterations would require software-based calibration to compensate for the observed offset, combined with digital signal processing to attenuate the noise-induced fluctuations visible in the current dataset.

These error characteristics align with findings reported by Juwita Mohd Sultan *et al*. (2022), who noted that while the MPU6050 performs adequately as a low-cost instrument, its raw output contains substantial noise that degrades inertial measurement accuracy without proper filtration. Pranav Swarup Kumar *et al*. (2024) further showed that estimation algorithms such as the Kalman Filter are not merely beneficial but effectively necessary for controlling drift and minimizing signal disturbance in the MPU6050 module — the improvement in angular stability over raw accelerometer data is, by their account, substantial. Taken together, these findings suggest that the current system's measurement limitations are well-understood and technically addressable, provided that appropriate filtering and calibration mechanisms are incorporated in subsequent development stages.

4. Discussion

The proposed system — an IoT-based room inclination monitor pairing the MPU6050 sensor with an ESP32 microcontroller — shows a clear capacity to synthesize measurement data and render both horizontal and vertical surface conditions in a meaningful way. The combined wall-to-floor angle recorded by the system was 88.06°, a value that approximates the ideal 90° right angle closely enough to confirm the system's conceptual validity. The measurement process draws on acceleration vectors derived from fundamental mechanical principles: an object's orientation relative to gravity can be inferred from the distribution of acceleration across axes. The measured angle of 88.88° reflects a minor deviation from the ideal, attributable to sensor noise, imperfect device placement, and environmental disturbances during acquisition. Minor, yes — but not negligible, particularly if the system is ever deployed in contexts where angular precision directly informs structural decisions.

A closer look at the measurement mechanism shows that angular readings depend heavily on how Earth's gravitational vector distributes across the X, Y, and Z axes as captured by the MPU6050 accelerometer. During floor testing (Figure 6), an initial reference dataset is established to anchor static acceleration measurements on the horizontal plane. Raw sensor outputs are converted to gravitational units (g) by dividing values by a scale factor of 16,384 — corresponding to the ±2g measurement range configuration. This approach aligns with the position taken by Sasmoko *et al*. (2021), who argued that sensor stability under static conditions is a prerequisite for minimizing errors in inclination angle calculations relative to Earth's center of mass. What that means in practice is that any instability during the reference acquisition stage propagates directly into every subsequent angular calculation — a compounding effect that the current system does not yet account for.

Treating wall and floor planes jointly within a right-angle configuration yields a more grounded spatial reading than any single-plane measurement could provide. The geometric relationship between two reference surfaces adds interpretive depth that a solitary plane simply cannot offer. The minor discrepancy between measured and theoretical values can be traced to several contextual factors: sensor mounting tolerances, ambient vibrations, and the limited resolution of the sensor in detecting very small orientation changes. Prior work by Nayyer Nayab Malik *et al*. (2022) examined IMU-based measurements using the MPU6050 in small-scale experimental setups involving two-dimensional rotational motion and real-time data analysis, confirming the sensor's applicability under controlled conditions. The proposed system, by extension, is capable of providing a spatially grounded reading — one particularly relevant for structural evaluation and room inclination inspection.

Sensor mounting configurations are known to influence measurement accuracy in joint angular motion capture (Karina Lebel *et al*., 2017), and performance tends to degrade under more complex dynamic conditions (Alison Godwin *et al*., 2009). These are not incidental limitations — they are structural characteristics of sensor- and network-based measurement systems that must be factored into any honest interpretation of the results. The system performs well within the boundaries of its current design. Whether those boundaries are sufficient depends entirely on the application — and that question deserves more rigorous attention in future work.

5. Conclusion

The IoT-based angular measurement system developed in this study demonstrates a functional capacity to identify the inclination relationship between vertical and horizontal planes within an enclosed space. Experimental results yielded a combined wall-to-floor angle of 88.06° — close to the ideal 90° right angle — confirming that the system can represent the geometric conditions of a room with reasonable fidelity. These findings support the broader proposition that sensor-based measurement integrated with network communication can serve as a viable digital alternative for angular measurement applications, particularly where conventional instrumentation is either impractical or cost-prohibitive.

That said, several limitations were identified that temper a straightforward endorsement of the current implementation. The sensor's sensitivity to environmental vibrations, combined with the absence of digital filtering and the difficulty of maintaining consistent device placement across trials, collectively introduced measurement instability that manifested as a systematic offset below the 90° reference. These are not peripheral concerns — they represent the primary gap between the system's demonstrated capability and the precision standard required for structural health monitoring or construction quality assessment. Further experimental evaluation under varying environmental conditions and different sensor placement configurations is necessary before the system's accuracy and consistency can be considered adequate for deployment in demanding contexts. Despite these limitations, the system shows genuine potential for development across a range of practical applications: building construction quality assessment, structural tilt monitoring, and automated geometric inspection of indoor spaces. Targeted improvements — particularly in signal filtering, calibration offset correction, and hardware refinement —

would meaningfully close the gap between current performance and application-grade reliability. As a low-cost, network-integrated measurement platform, the system offers a credible foundation for supporting angular monitoring requirements in modern building environments, provided that the identified technical shortcomings are addressed with appropriate rigor in subsequent iterations.

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