Motor Predictive Maintenance - Real-Time Data Analysis v2

Data Format Support

This notebook automatically detects and handles both data formats:

Format 1 (No timestamps):

```
ax_g,ay_g,az_g,temp_C
```

Format 2 (With timestamps - from data_collection_with_timestamps.py):

```
timestamp,ax_g,ay_g,az_g,temp_C
```

Timestamp Formats Supported:

- **Unix timestamps** (recommended): Numeric seconds since epoch (e.g., `1731254515.059`) - compact and optimal for feature extraction
- **ISO format**: Date-time strings (e.g., `2025-11-10 18:41:55.059`)
- **Other formats**: Automatically detected and normalized

Note: Microphone data has been removed. This notebook analyzes accelerometer and temperature data only.

In [1]:
```
# Import libraries
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
import seaborn as sns
from scipy import stats
from scipy.fft import fft, fftfreq
from datetime import datetime

plt.style.use('seaborn-v0_8-darkgrid')
sns.set_palette('husl')
%matplotlib inline

import warnings
warnings.filterwarnings('ignore')
```

```
print('✓ Libraries loaded successfully')
```

```
✓ Libraries loaded successfully
```

1. Smart Data Loading (Auto-detects format)

In [2]:
```
# Load data - automatically detect format and normalize timestamps
def load_motor_data(filename='motor_data_20251110_goodmotorlados.csv'):
    """Smart loader that handles both formats and normalizes timestamps"""

    # Try to read first few lines to detect format
    with open(filename, 'r') as f:
        first_line = f.readline().strip()
        second_line = f.readline().strip()
        third_line = f.readline().strip()

    # Count commas to determine number of columns
    num_cols = first_line.count(',') + 1

    if num_cols == 5:  # Has timestamps: timestamp,ax_g,ay_g,az_g,temp_C
        print("✓ Detected format: WITH timestamps")
        df = pd.read_csv(filename)

        # Check timestamp format
        first_ts = df['timestamp'].iloc[0]
        first_ts_str = str(first_ts)
        second_ts_str = str(df['timestamp'].iloc[1])

        # Check if timestamps are Unix timestamps (numeric, large values > 1000000000)
        is_unix_timestamp = False
        try:
            first_ts_float = float(first_ts)
            # Unix timestamps are typically > 1000000000 (year 2001) and < 9999999999 (year 2286)
            if first_ts_float > 1000000000 and first_ts_float < 9999999999:
                is_unix_timestamp = True
        except (ValueError, TypeError):
            pass

        # Check if timestamps are in ISO format (YYYY-MM-DD)
        is_iso_format = not is_unix_timestamp and '-' in first_ts_str and first_ts_str.count('-') == 2 and len(first_ts

        # Check if first timestamp has date and second doesn't (inconsistent format)
        needs_normalization = not is_unix_timestamp and '/' in first_ts_str and ' ' in first_ts_str and ':' in second_t

        if needs_normalization:
```

```
        print("⚠️  Detected inconsistent timestamp format - normalizing...")

        # Parse first timestamp to extract date and hour
        try:
            # First timestamp format: "10/11/25 18:41" or similar
            first_parts = first_ts.split(' ')
            date_part = first_parts[0]  # "10/11/25"
            time_part = first_parts[1] if len(first_parts) > 1 else "00:00"  # "18:41"

            # Extract hour from first timestamp
            hour_min = time_part.split(':')
            base_hour = hour_min[0]  # "18"

            # Normalize all timestamps
            normalized_timestamps = []
            for idx, ts in enumerate(df['timestamp']):
                ts_str = str(ts)

                if '/' in ts_str and ' ' in ts_str:
                    # Full timestamp with date - check if it has seconds
                    if ts_str.count(':') == 1:
                        # Only has hour:minute, add seconds
                        normalized_timestamps.append(f"{ts_str}:00.0")
                    else:
                        # Already has seconds - use as is
                        normalized_timestamps.append(ts_str)
                elif ':' in ts_str and '/' not in ts_str:
                    # Time only - prepend date and hour
                    # Format: "41:55.1" -> "10/11/25 18:41:55.1"
                    time_only = ts_str
                    if '.' in time_only:
                        # Has milliseconds: "41:55.1"
                        normalized_ts = f"{date_part} {base_hour}:{time_only}"
                    else:
                        # No milliseconds: "41:55"
                        normalized_ts = f"{date_part} {base_hour}:{time_only}.0"
                    normalized_timestamps.append(normalized_ts)
                else:
                    # Fallback - try to parse as is
                    normalized_timestamps.append(ts_str)

            df['timestamp'] = normalized_timestamps
            print(f"✓ Normalized {len(normalized_timestamps)} timestamps")

        except Exception as e:
            print(f"⚠️  Warning: Could not normalize timestamps: {e}")
            print("   Attempting to parse as-is...")
```

```python
        # Convert to datetime or handle Unix timestamps
        try:
            # Save original timestamps before parsing
            original_timestamps = df['timestamp'].copy()

            if is_unix_timestamp:
                # Unix timestamp format - convert to datetime and calculate elapsed time
                print("✓ Detected Unix timestamp format (seconds since epoch)")
                df['timestamp'] = pd.to_datetime(original_timestamps, unit='s', errors='coerce')
                # Calculate elapsed time directly from Unix timestamps (more precise)
                df['elapsed_sec'] = original_timestamps.astype(float) - original_timestamps.iloc[0]
                print("✓ Timestamps converted to datetime, elapsed time calculated")
            elif is_iso_format:
                # ISO format - pandas can parse this directly
                print("✓ Detected ISO format timestamps (YYYY-MM-DD)")
                df['timestamp'] = pd.to_datetime(original_timestamps, errors='coerce')
                df['elapsed_sec'] = (df['timestamp'] - df['timestamp'].iloc[0]).dt.total_seconds()
            else:
                # Try multiple date formats for other formats
                df['timestamp'] = pd.to_datetime(original_timestamps, format='%d/%m/%y %H:%M:%S.%f', errors='coerce')
                if df['timestamp'].isna().any():
                    # Try alternative format without milliseconds
                    df['timestamp'] = pd.to_datetime(original_timestamps, format='%d/%m/%y %H:%M:%S', errors='coerce')
                if df['timestamp'].isna().any():
                    # Try standard format (pandas auto-detection)
                    df['timestamp'] = pd.to_datetime(original_timestamps, errors='coerce')
                df['elapsed_sec'] = (df['timestamp'] - df['timestamp'].iloc[0]).dt.total_seconds()

            # Check if conversion was successful
            if df['timestamp'].isna().any():
                print(f"⚠️  Warning: {df['timestamp'].isna().sum()} timestamps could not be parsed")
            else:
                print("✓ All timestamps parsed successfully")

        except Exception as e:
            print(f"⚠️  Warning: Error parsing timestamps: {e}")
            print("   Timestamps may not be usable for time-based analysis")

        df['reading_num'] = range(1, len(df) + 1)
        has_timestamps = True
        has_timestamps = True

    elif num_cols == 4:  # No timestamps: ax_g,ay_g,az_g,temp_C
        print("✓ Detected format: WITHOUT timestamps")
        df = pd.read_csv(filename, header=None, names=['ax_g', 'ay_g', 'az_g', 'temp_C'])
        df['reading_num'] = range(1, len(df) + 1)
        has_timestamps = False
```

```python
    else:
        raise ValueError(f"Unexpected format: {num_cols} columns found. Expected 4 (no timestamp) or 5 (with timestamp)

    return df, has_timestamps

# Load the data
df, has_timestamps = load_motor_data('motor_data_20251110_goodmotorlados.csv')

print(f"\n📊 Data Summary")
print("=" * 60)
print(f"Total readings: {len(df)}")
print(f"Columns: {list(df.columns)}")
if has_timestamps:
    duration = df['elapsed_sec'].max()
    print(f"Duration: {duration:.1f} seconds ({duration/60:.1f} minutes)")
    print(f"Sampling rate: {len(df)/duration:.2f} Hz")
    print(f"Start time: {df['timestamp'].iloc[0]}")
    print(f"End time: {df['timestamp'].iloc[-1]}")
print("=" * 60)

df.head(10)
```

```
✓ Detected format: WITH timestamps
✓ Detected Unix timestamp format (seconds since epoch)
✓ Timestamps converted to datetime, elapsed time calculated
✓ All timestamps parsed successfully

📊 Data Summary
============================================================
Total readings: 29837
Columns: ['timestamp', 'ax_g', 'ay_g', 'az_g', 'temp_C', 'elapsed_sec', 'reading_num']
Duration: 59.7 seconds (1.0 minutes)
Sampling rate: 500.02 Hz
Start time: 2025-11-10 18:41:55.059000015
End time: 2025-11-10 18:42:54.730999947
============================================================
```

Out[2]:

	timestamp	ax_g	ay_g	az_g	temp_C	elapsed_sec	reading_num
0	2025-11-10 18:41:55.059000015	-0.072	-0.995	0.020	24.91	0.000	1
1	2025-11-10 18:41:55.061000109	-0.036	-0.994	-0.027	24.91	0.002	2
2	2025-11-10 18:41:55.062999964	-0.119	-1.019	0.011	24.91	0.004	3
3	2025-11-10 18:41:55.065000057	-0.041	-1.029	0.038	24.91	0.006	4
4	2025-11-10 18:41:55.066999911	0.024	-0.947	-0.063	24.91	0.008	5
5	2025-11-10 18:41:55.069000006	0.022	-0.963	-0.082	24.91	0.010	6
6	2025-11-10 18:41:55.071000099	0.002	-0.992	-0.024	24.91	0.012	7
7	2025-11-10 18:41:55.072999954	-0.007	-0.996	0.077	24.91	0.014	8
8	2025-11-10 18:41:55.075000048	-0.101	-1.054	0.095	24.91	0.016	9
9	2025-11-10 18:41:55.076999903	-0.011	-0.975	0.036	24.91	0.018	10

2. Data Quality & Statistics

In [3]:

```
# Check for missing values
print("Missing Values:")
print(df.isnull().sum())
print("\n" + "="*60 + "\n")

# Statistical summary
print("Statistical Summary:")
df[['ax_g', 'ay_g', 'az_g', 'temp_C']].describe()
```

```
Missing Values:
timestamp      0
ax_g           0
ay_g           0
az_g           0
temp_C         0
elapsed_sec    0
reading_num    0
dtype: int64

============================================================

Statistical Summary:
```

Out[3]:

	ax_g	ay_g	az_g	temp_C
count	29837.000000	29837.000000	29837.000000	29837.000000
mean	-0.021301	-0.997291	-0.003267	25.822595
std	0.050905	0.031942	0.047907	1.439802
min	-0.221000	-1.141000	-0.221000	24.690000
25%	-0.055000	-1.019000	-0.035000	25.010000
50%	-0.021000	-0.997000	-0.004000	25.230000
75%	0.012000	-0.976000	0.029000	25.470000
max	0.194000	-0.867000	0.199000	29.070000

In [4]:

```
# Calculate vibration magnitude
df['vibration_magnitude'] = np.sqrt(df['ax_g']**2 + df['ay_g']**2 + df['az_g']**2)

# Identify anomalies
print("🚨 Anomaly Detection:\n")

# High vibration (>1.5g)
accel_threshold = 1.5
high_vib = df[df['vibration_magnitude'] > accel_threshold]

if len(high_vib) > 0:
    print(f"⚠️  High Vibration Events: {len(high_vib)} readings (>{accel_threshold}g)")
    if has_timestamps:
        display(high_vib[['timestamp', 'vibration_magnitude', 'ax_g', 'ay_g', 'az_g', 'temp_C']].head(10))
    else:
        display(high_vib[['reading_num', 'vibration_magnitude', 'ax_g', 'ay_g', 'az_g', 'temp_C']].head(10))
else:
    print("✅ No high vibration events detected")

# Temperature extremes
temp_high = df[df['temp_C'] > 32]
if len(temp_high) > 0:
    print(f"\n🌡️  High Temperature Events: {len(temp_high)} readings (>32°C)")
    print(f"   Max: {df['temp_C'].max():.2f}°C")
else:
    print(f"\n✅ Temperature within normal range (max: {df['temp_C'].max():.2f}°C)")
```

🚨 Anomaly Detection:

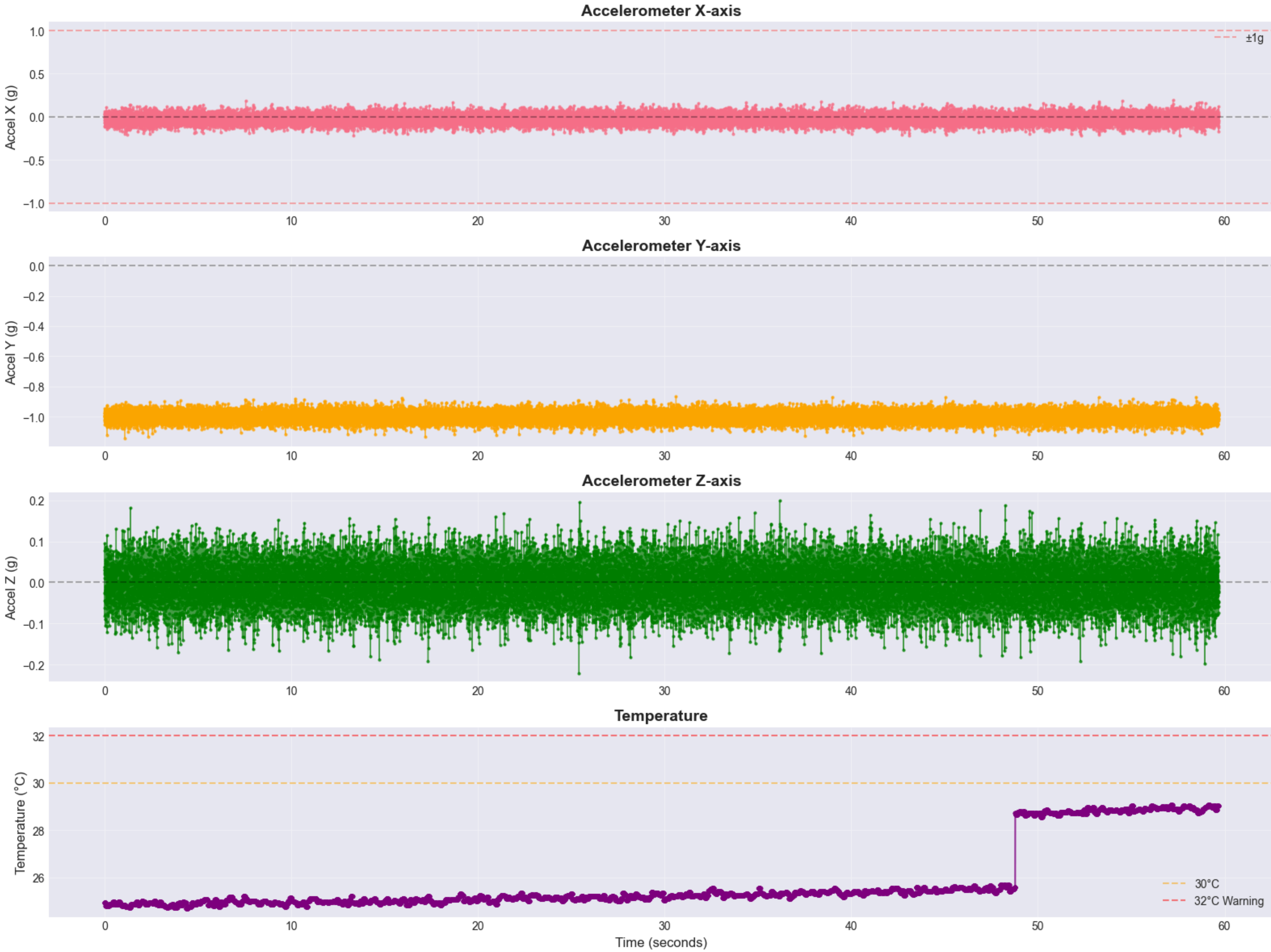
✅ No high vibration events detected

✅ Temperature within normal range (max: 29.07°C)

3. Time Series Visualization

In [5]:
```
# Determine x-axis (timestamp or reading number)
x_axis = 'elapsed_sec' if has_timestamps else 'reading_num'
x_label = 'Time (seconds)' if has_timestamps else 'Reading Number'

fig, axes = plt.subplots(4, 1, figsize=(16, 12))

# Accelerometer X
axes[0].plot(df[x_axis], df['ax_g'], marker='o', markersize=2, linewidth=1, alpha=0.7)
axes[0].axhline(y=0, color='k', linestyle='--', alpha=0.3)
axes[0].axhline(y=1, color='r', linestyle='--', alpha=0.3, label='±1g')
axes[0].axhline(y=-1, color='r', linestyle='--', alpha=0.3)
axes[0].set_ylabel('Accel X (g)', fontsize=12)
axes[0].set_title('Accelerometer X-axis', fontsize=14, fontweight='bold')
axes[0].legend()
axes[0].grid(True, alpha=0.3)

# Accelerometer Y
axes[1].plot(df[x_axis], df['ay_g'], marker='o', markersize=2, linewidth=1, alpha=0.7, color='orange')
axes[1].axhline(y=0, color='k', linestyle='--', alpha=0.3)
axes[1].set_ylabel('Accel Y (g)', fontsize=12)
axes[1].set_title('Accelerometer Y-axis', fontsize=14, fontweight='bold')
axes[1].grid(True, alpha=0.3)

# Accelerometer Z
axes[2].plot(df[x_axis], df['az_g'], marker='o', markersize=2, linewidth=1, alpha=0.7, color='green')
axes[2].axhline(y=0, color='k', linestyle='--', alpha=0.3)
axes[2].set_ylabel('Accel Z (g)', fontsize=12)
axes[2].set_title('Accelerometer Z-axis', fontsize=14, fontweight='bold')
axes[2].grid(True, alpha=0.3)

# Temperature
axes[3].plot(df[x_axis], df['temp_C'], marker='o', markersize=3, linewidth=1.5, alpha=0.8, color='purple')
axes[3].axhline(y=30, color='orange', linestyle='--', alpha=0.5, label='30°C')
axes[3].axhline(y=32, color='red', linestyle='--', alpha=0.5, label='32°C Warning')
axes[3].set_ylabel('Temperature (°C)', fontsize=12)
axes[3].set_xlabel(x_label, fontsize=12)
axes[3].set_title('Temperature', fontsize=14, fontweight='bold')
axes[3].legend()
```

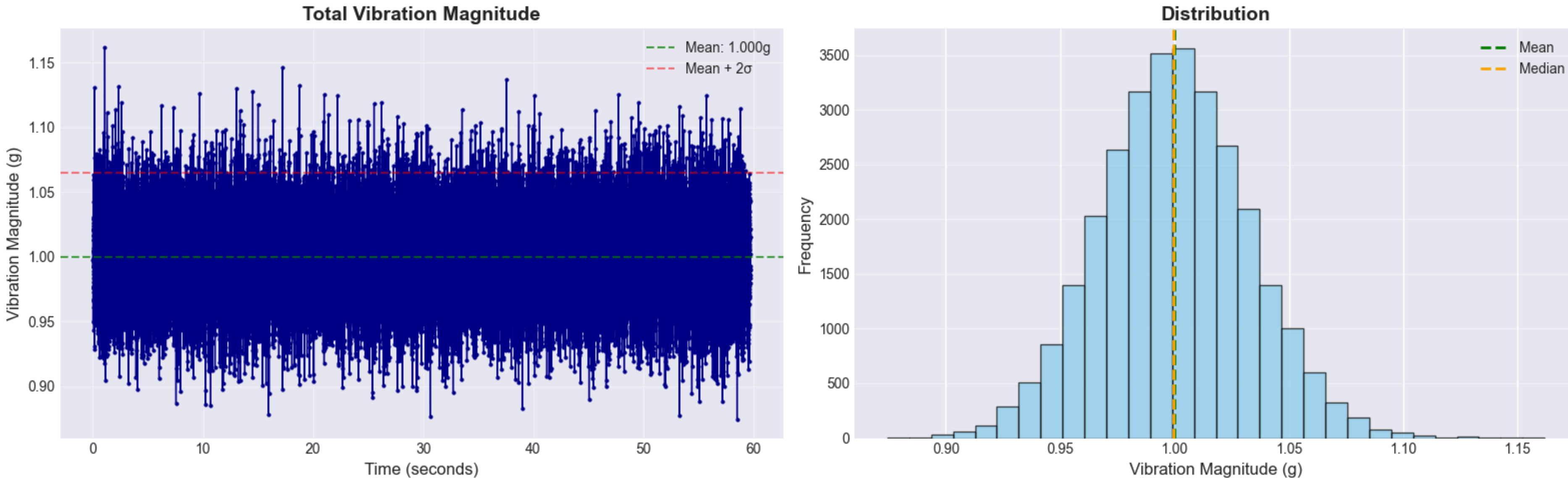
```python
axes[3].grid(True, alpha=0.3)

plt.tight_layout()
plt.show()
```



4. Vibration Analysis

In [6]:

```
fig, axes = plt.subplots(1, 2, figsize=(16, 5))

# Vibration over time
axes[0].plot(df[x_axis], df['vibration_magnitude'], marker='o', markersize=2, linewidth=1, color='darkblue')
axes[0].axhline(y=df['vibration_magnitude'].mean(), color='green', linestyle='--',
                alpha=0.7, label=f"Mean: {df['vibration_magnitude'].mean():.3f}g")
axes[0].axhline(y=df['vibration_magnitude'].mean() + 2*df['vibration_magnitude'].std(),
                color='red', linestyle='--', alpha=0.5, label='Mean + 2σ')
axes[0].set_xlabel(x_label, fontsize=12)
axes[0].set_ylabel('Vibration Magnitude (g)', fontsize=12)
axes[0].set_title('Total Vibration Magnitude', fontsize=14, fontweight='bold')
axes[0].legend()
axes[0].grid(True, alpha=0.3)

# Distribution
axes[1].hist(df['vibration_magnitude'], bins=30, edgecolor='black', alpha=0.7, color='skyblue')
axes[1].axvline(x=df['vibration_magnitude'].mean(), color='green', linestyle='--', linewidth=2, label='Mean')
axes[1].axvline(x=df['vibration_magnitude'].median(), color='orange', linestyle='--', linewidth=2, label='Median')
axes[1].set_xlabel('Vibration Magnitude (g)', fontsize=12)
axes[1].set_ylabel('Frequency', fontsize=12)
axes[1].set_title('Distribution', fontsize=14, fontweight='bold')
axes[1].legend()
axes[1].grid(True, alpha=0.3, axis='y')

plt.tight_layout()
plt.show()

print(f"Vibration Statistics:")
print(f"  Mean: {df['vibration_magnitude'].mean():.4f}g")
print(f"  Std:  {df['vibration_magnitude'].std():.4f}g")
print(f"  Max:  {df['vibration_magnitude'].max():.4f}g")
```



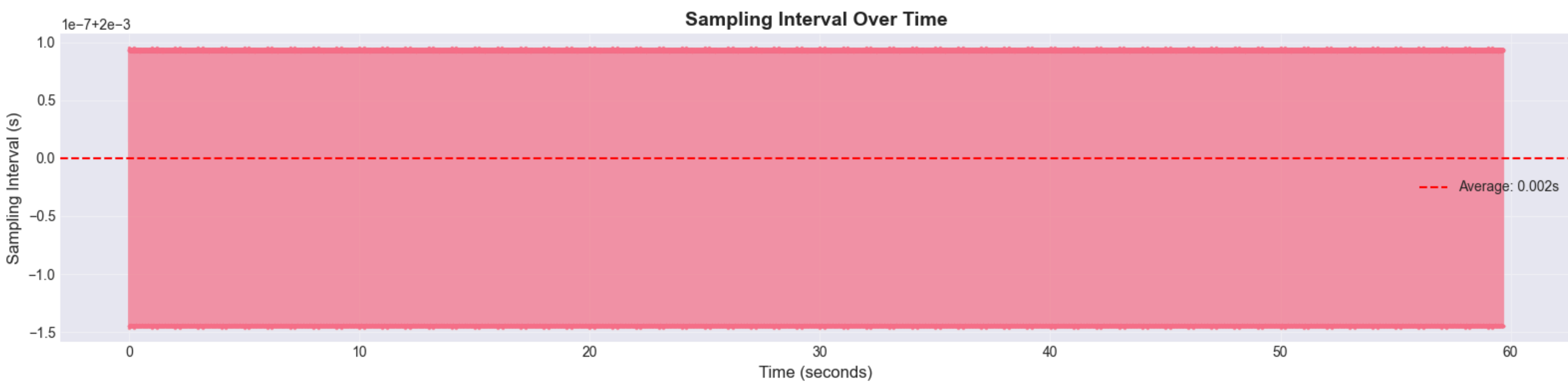

```
Vibration Statistics:
  Mean: 1.0000g
  Std:  0.0325g
  Max:  1.1617g
```

5. Time-Based Analysis (if timestamps available)

In [7]:
```
if has_timestamps:
    print("⏱  TIME-BASED ANALYSIS\n")

    # Calculate sampling rate
    time_diffs = df['timestamp'].diff().dt.total_seconds()
    avg_interval = time_diffs.mean()
    actual_sampling_rate = 1 / avg_interval if avg_interval > 0 else 0

    print(f"Actual Sampling Rate: {actual_sampling_rate:.2f} Hz")
    print(f"Average interval: {avg_interval:.3f} seconds")
    print(f"Min interval: {time_diffs.min():.3f} seconds")
    print(f"Max interval: {time_diffs.max():.3f} seconds")

    # Plot sampling intervals
    fig, ax = plt.subplots(figsize=(16, 4))
    ax.plot(df['elapsed_sec'][1:], time_diffs[1:], marker='.', markersize=3, alpha=0.7)
    ax.axhline(y=avg_interval, color='red', linestyle='--', label=f'Average: {avg_interval:.3f}s')
    ax.set_xlabel('Time (seconds)', fontsize=12)
    ax.set_ylabel('Sampling Interval (s)', fontsize=12)
    ax.set_title('Sampling Interval Over Time', fontsize=14, fontweight='bold')
    ax.legend()
    ax.grid(True, alpha=0.3)
```

```
    plt.tight_layout()
    plt.show()

    # Calculate rates of change
    df['temp_rate'] = df['temp_C'].diff() / time_diffs
    df['vibration_rate'] = df['vibration_magnitude'].diff() / time_diffs

    print(f"\n📈 Rates of Change:")
    print(f"  Temperature: {df['temp_rate'].mean():.4f} °C/s")
    print(f"  Max temp increase: {df['temp_rate'].max():.4f} °C/s")
    print(f"  Max temp decrease: {df['temp_rate'].min():.4f} °C/s")

else:
    print("ℹ️  No timestamps available. Add timestamps for time-based analysis.")
    print("   Use the provided data_collection_with_timestamps.py script!")
```

```
⏱  TIME-BASED ANALYSIS

Actual Sampling Rate: 500.00 Hz
Average interval: 0.002 seconds
Min interval: 0.002 seconds
Max interval: 0.002 seconds
```



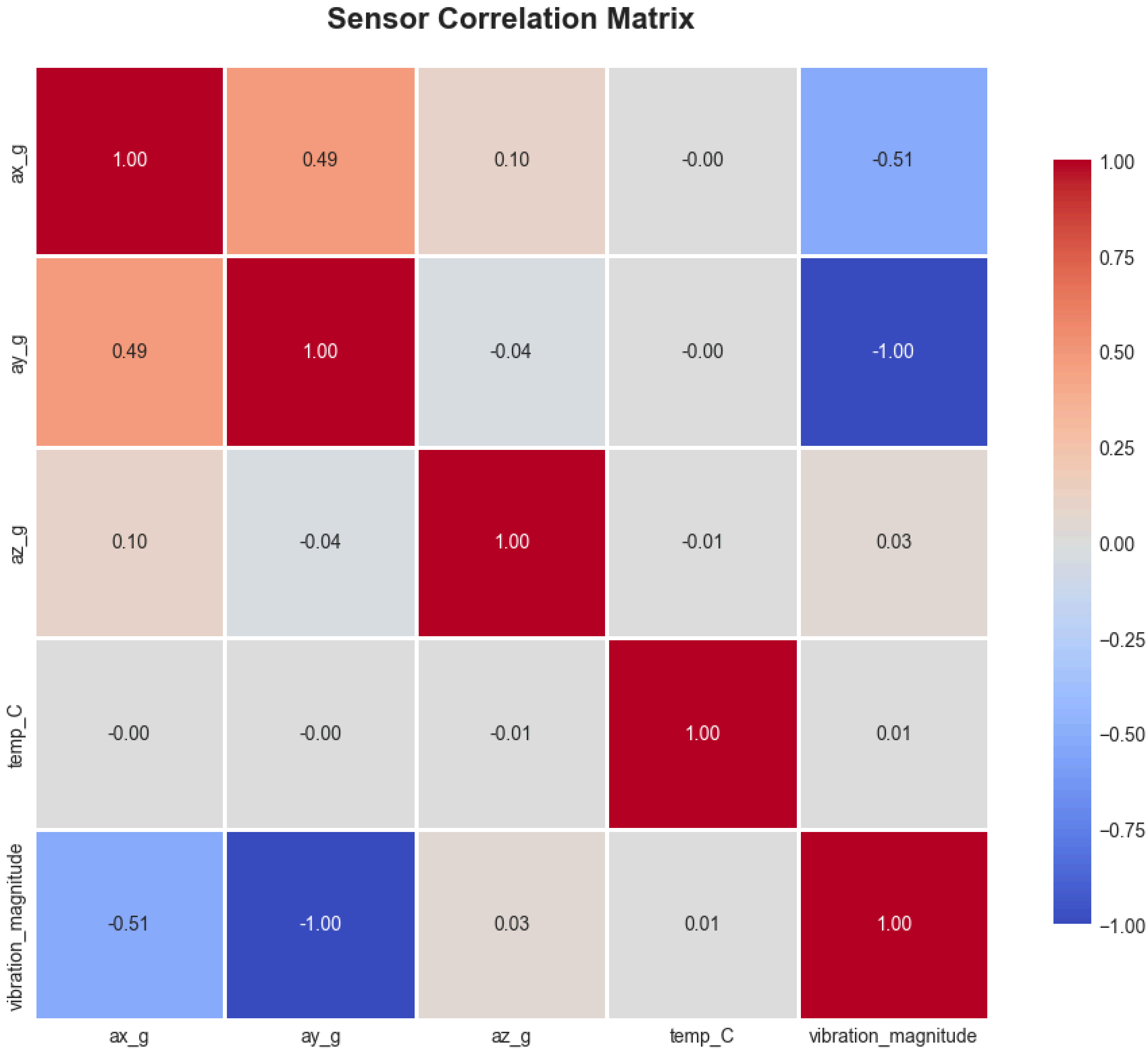

```
📈 Rates of Change:
  Temperature: 0.0690 °C/s
  Max temp increase: 1569.9262 °C/s
  Max temp decrease: -150.0109 °C/s
```

6. Correlation Analysis

In [8]:

```
corr_cols = ['ax_g', 'ay_g', 'az_g', 'temp_C', 'vibration_magnitude']
corr_matrix = df[corr_cols].corr()

plt.figure(figsize=(10, 8))
```

```
sns.heatmap(corr_matrix, annot=True, cmap='coolwarm', center=0,
            square=True, linewidths=2, cbar_kws={"shrink": 0.8}, fmt='.2f',
            vmin=-1, vmax=1)
plt.title('Sensor Correlation Matrix', fontsize=16, fontweight='bold', pad=20)
plt.tight_layout()
plt.show()
```


Sensor Correlation Matrix
ax_g
ay_g
az_g
temp_C
vibration_magnitude
1.00
0.49
0.10
-0.00
-0.51
0.49
1.00
-0.04
-0.00
-1.00
0.10
-0.04
1.00
-0.01
0.03
-0.00
-0.00
-0.01
1.00
0.01
-0.51
-1.00
0.03
0.01
1.00
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
−1.00

7. Summary Report

In [9]:

```
print("="*70)
print(" MOTOR HEALTH SUMMARY REPORT")
print("="*70)

print(f"\n📊 Dataset:")
print(f"   Total Readings: {len(df)}")
if has_timestamps:
    print(f"   Duration: {df['elapsed_sec'].max()/60:.1f} minutes")
    print(f"   Sampling Rate: {actual_sampling_rate:.2f} Hz")

print(f"\n🔧 Vibration:")
print(f"   Mean: {df['vibration_magnitude'].mean():.4f}g")
print(f"   Std: {df['vibration_magnitude'].std():.4f}g")
print(f"   Max: {df['vibration_magnitude'].max():.4f}g")
high_count = len(df[df['vibration_magnitude'] > 1.5])
print(f"   High Events (>1.5g): {high_count} ({high_count/len(df)*100:.1f}%)")

print(f"\n🌡️  Temperature:")
print(f"   Current: {df['temp_C'].iloc[-1]:.2f}°C")
print(f"   Mean: {df['temp_C'].mean():.2f}°C")
print(f"   Range: {df['temp_C'].min():.2f}°C - {df['temp_C'].max():.2f}°C")

print(f"\n💡 Status:")
if high_count > 5:
    print("   ⚠️  CAUTION: Multiple high vibration events detected")
elif high_count > 0:
    print("   🟡 NORMAL: Some vibration spikes observed")
else:
    print("   ✅ GOOD: Vibration within normal range")

if df['temp_C'].max() > 35:
    print("   🔴 HIGH TEMPERATURE WARNING")
elif df['temp_C'].max() > 32:
    print("   🟡 Elevated temperature observed")
else:
    print("   ✅ Temperature nominal")

print("\n" + "="*70)
```

```
======================================================================
 MOTOR HEALTH SUMMARY REPORT
======================================================================

📊 Dataset:
   Total Readings: 29837
   Duration: 1.0 minutes
   Sampling Rate: 500.00 Hz

🔧 Vibration:
   Mean: 1.0000g
   Std: 0.0325g
   Max: 1.1617g
   High Events (>1.5g): 0 (0.0%)

🌡️ Temperature:
   Current: 29.03°C
   Mean: 25.82°C
   Range: 24.69°C - 29.07°C

💡 Status:
   ✅ GOOD: Vibration within normal range
   ✅ Temperature nominal

======================================================================
```

8. Export Data

In [10]:

```python
# Save processed data
df.to_csv('motor_data_processed.csv', index=False)
print('✓ Processed data saved: motor_data_processed.csv')

# Save summary
summary = df[['ax_g', 'ay_g', 'az_g', 'temp_C', 'vibration_magnitude']].describe()
summary.to_csv('motor_data_summary.csv')
print('✓ Summary saved: motor_data_summary.csv')
```

```
✓ Processed data saved: motor_data_processed.csv
✓ Summary saved: motor_data_summary.csv
```