High Resolution Vector Processing and IOT in PostgreSQL

Jun 6, 2018, Dallas, Texas, USA

John Scott
Founder, SetSpace, Inc, 1998-now

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Tacoma Bridge Collapse in Low Winds

Tacoma Narrows Bridge Collapse "Gallopin' Gertie"

Video of Tacoma Bridge Collapse (https://youtu.be/lXyG68_caV4?t=61)

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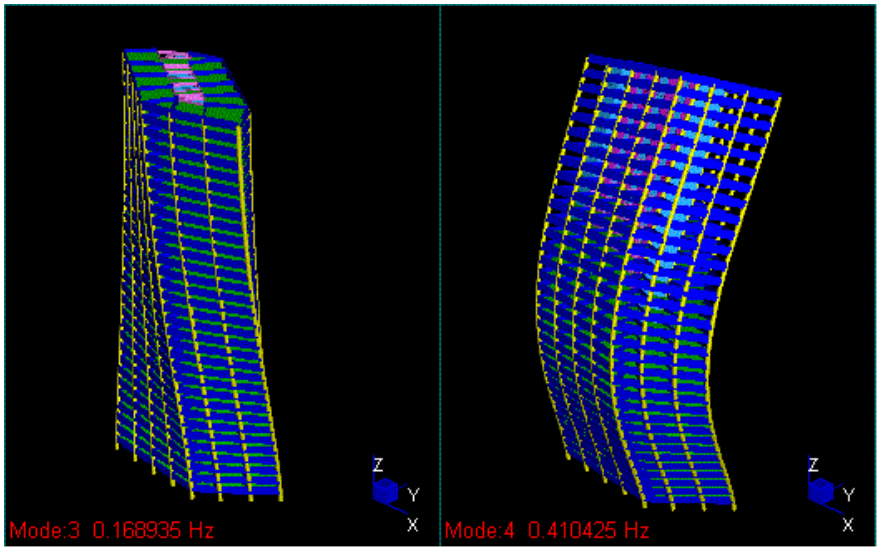
Flexible Structures Vibrate at Peculiar Frequencies

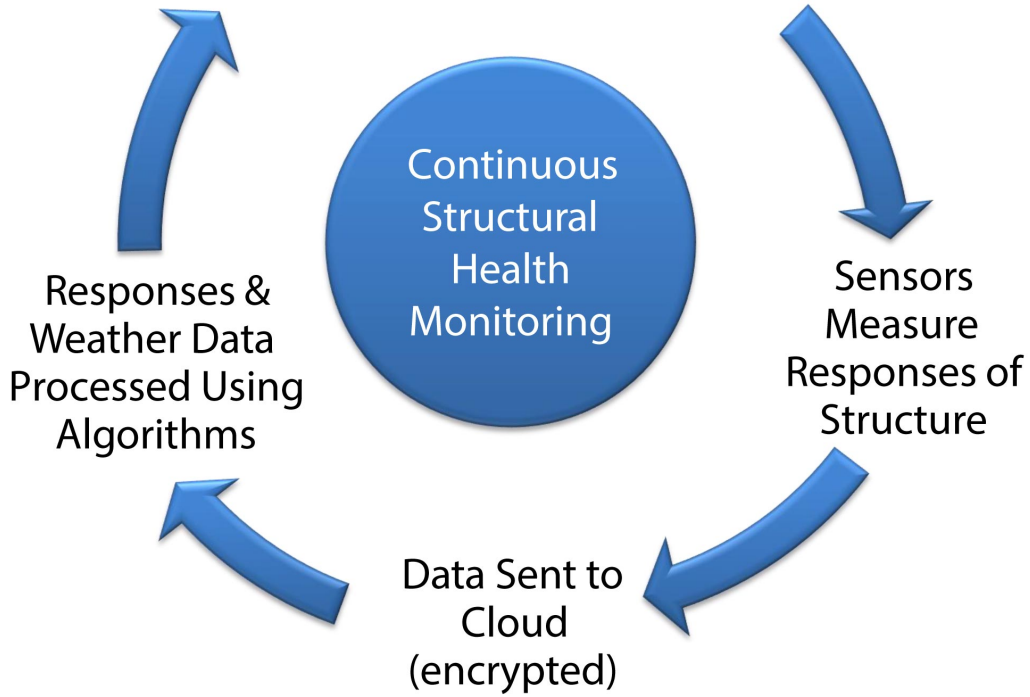


Small Energy Stress Certain Points, Like a Coat Hanger

Cycle of Monitoring of Flexible Structure

Web Based Access & Alarms

Install Sensor Unit on Structure and a GCU



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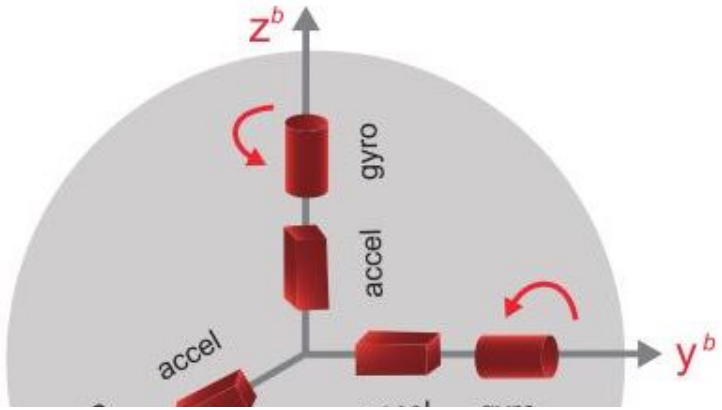
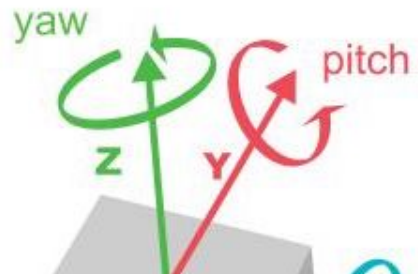
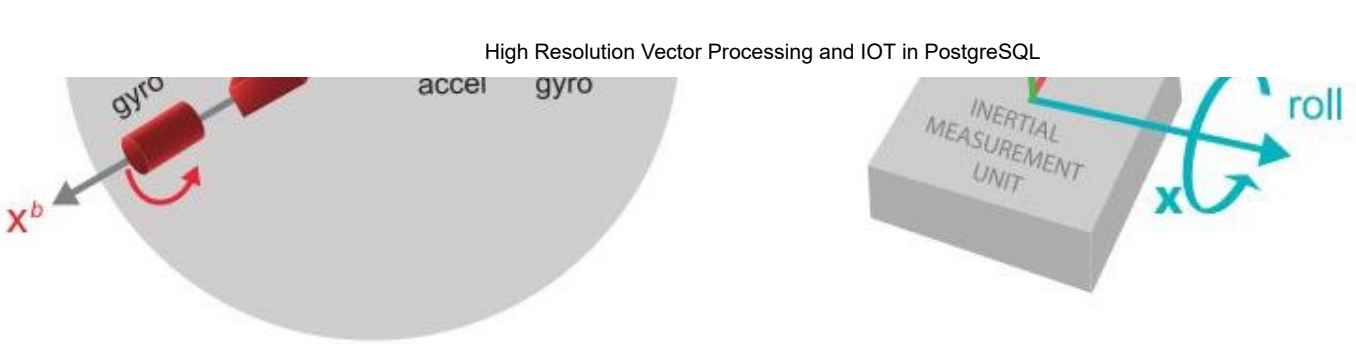
Cheap Inertial Measurement Units (IMU) Changed the World



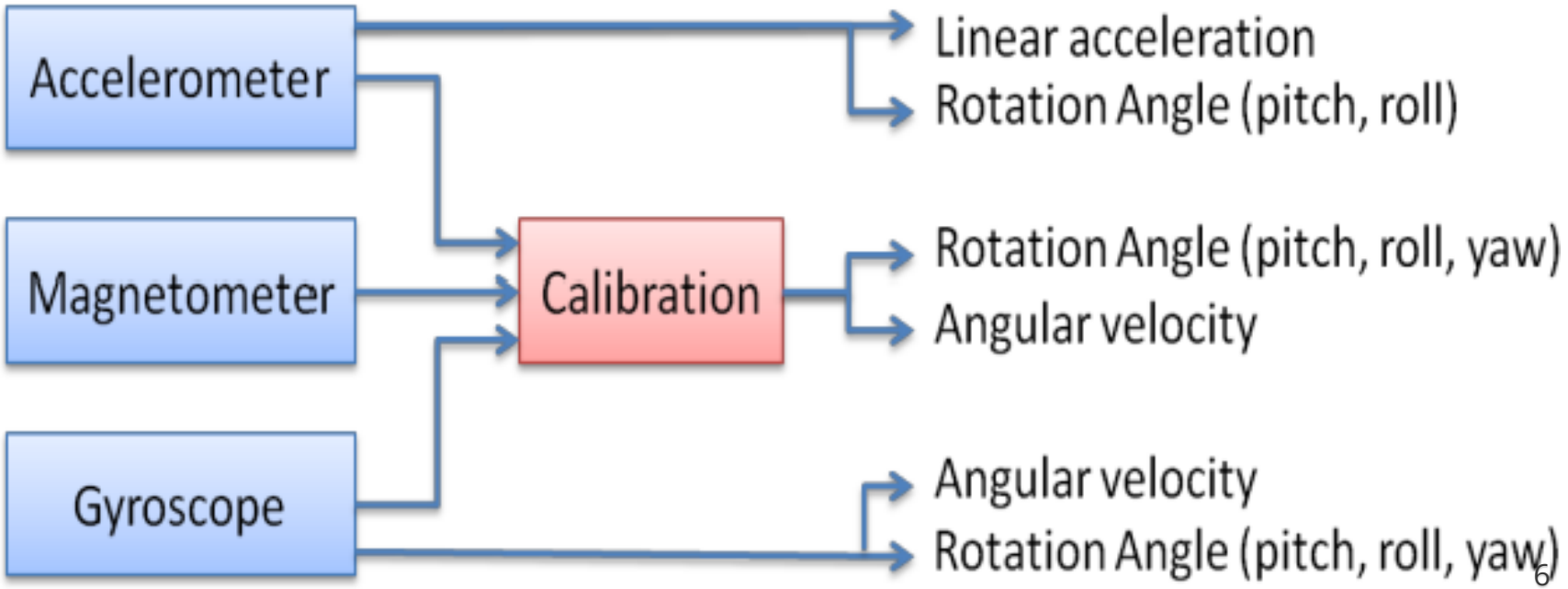




Inertial Measurement unit
3 accelerometers, 3 gyroscopes

Micro-Electro Mechanics Sensor (MEMS) In Smartphones, FitBit, Drones, Aircraft 5

Inside an IMU - Flow of Micro Electronic Mechanical Sensors (MEMS)



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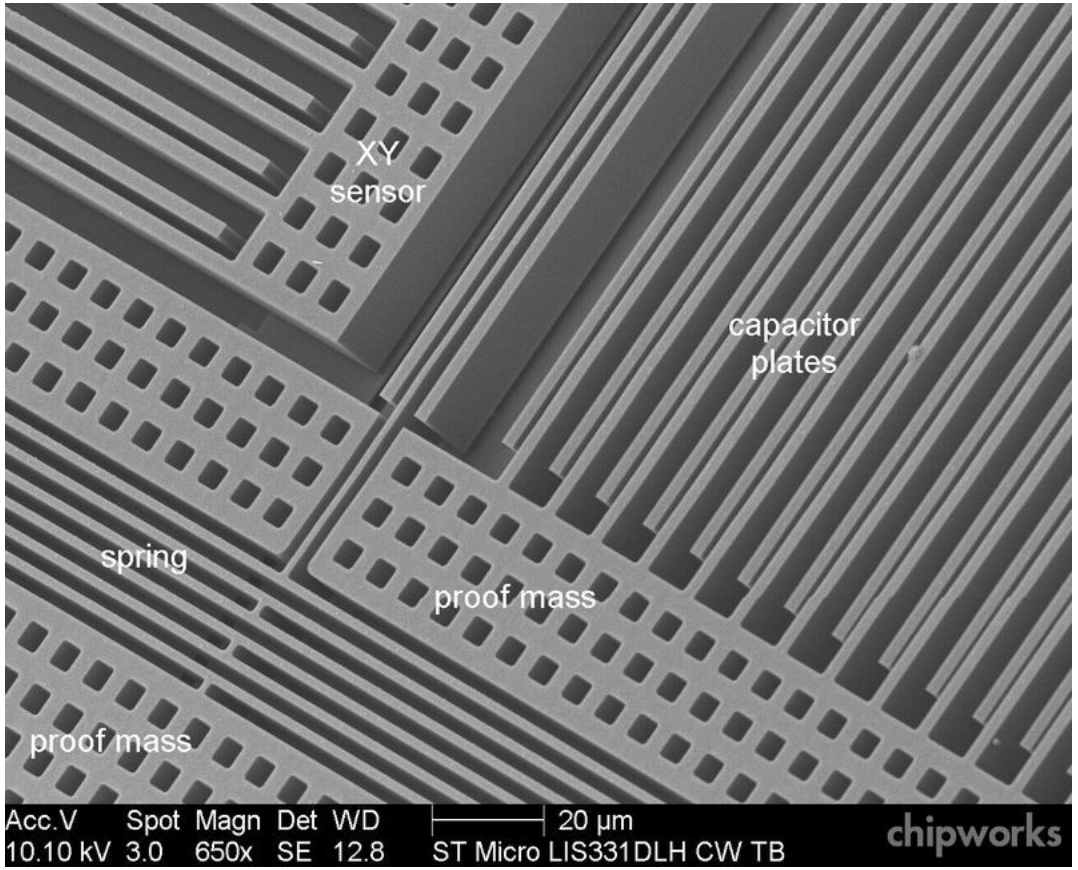
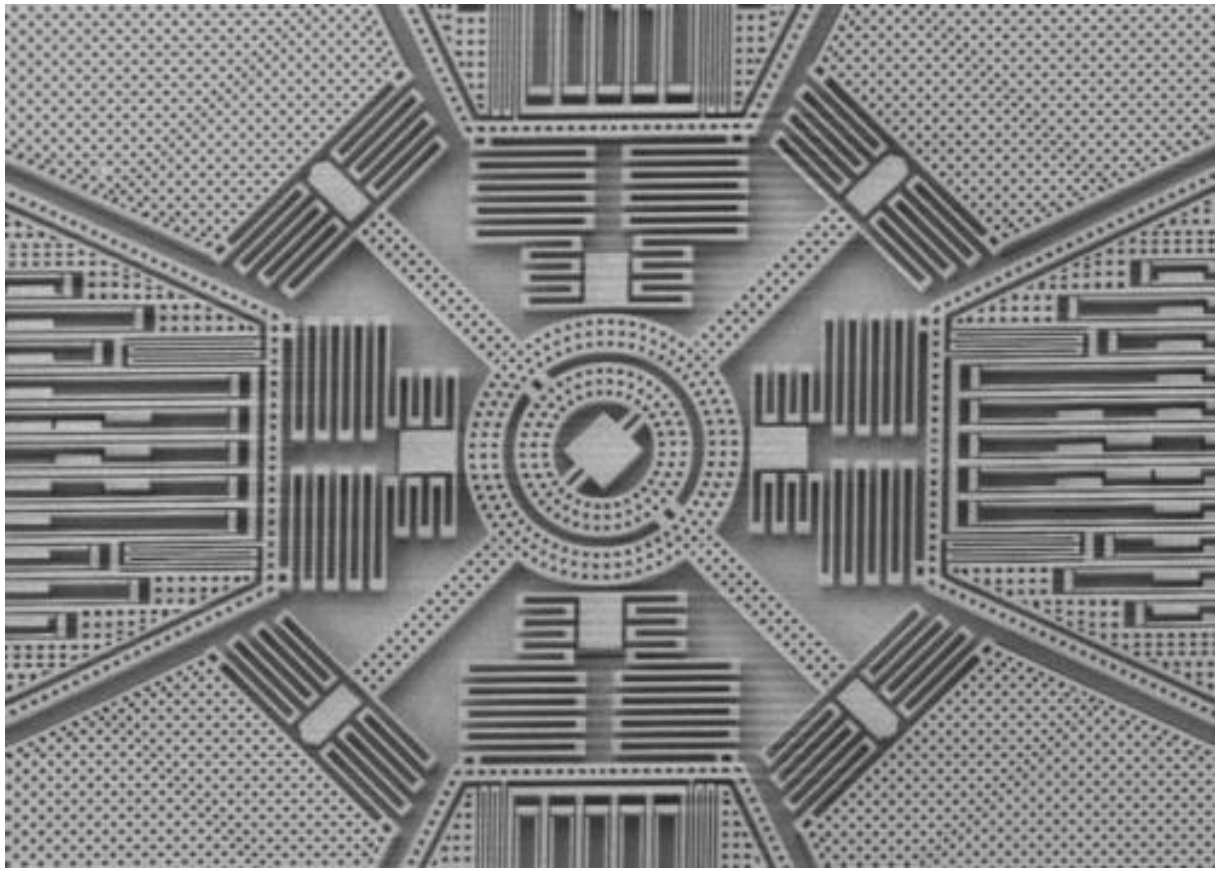
Linear Accelometer (MEMS) Viewed in Electron Microscope!



Angular Accelometer (MEMS) Viewed in Electron Microscope!



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VectorNav 300 with Gravitational and Magnetic Map of Earth

Ruggedized with 2 GPS External Antenna for Recalibrating the Integrated Kalman Filter 9

VectorNac 300 Fits in Your Hand - $800

Made in Dallas, Texas!

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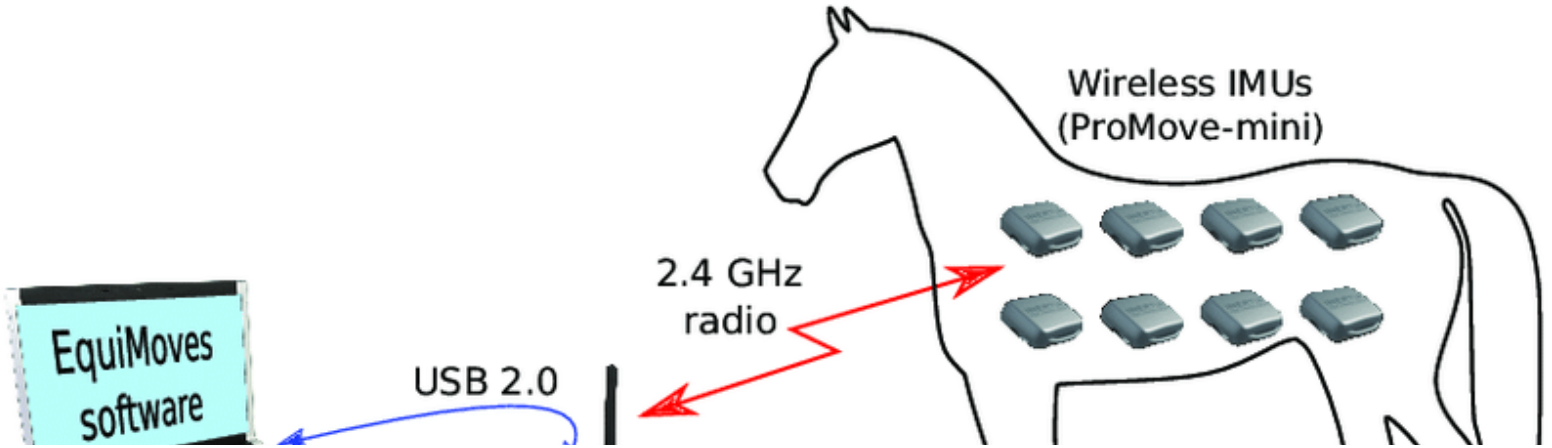
Inertial Measurement Units in Everything!



Inertia Gateway

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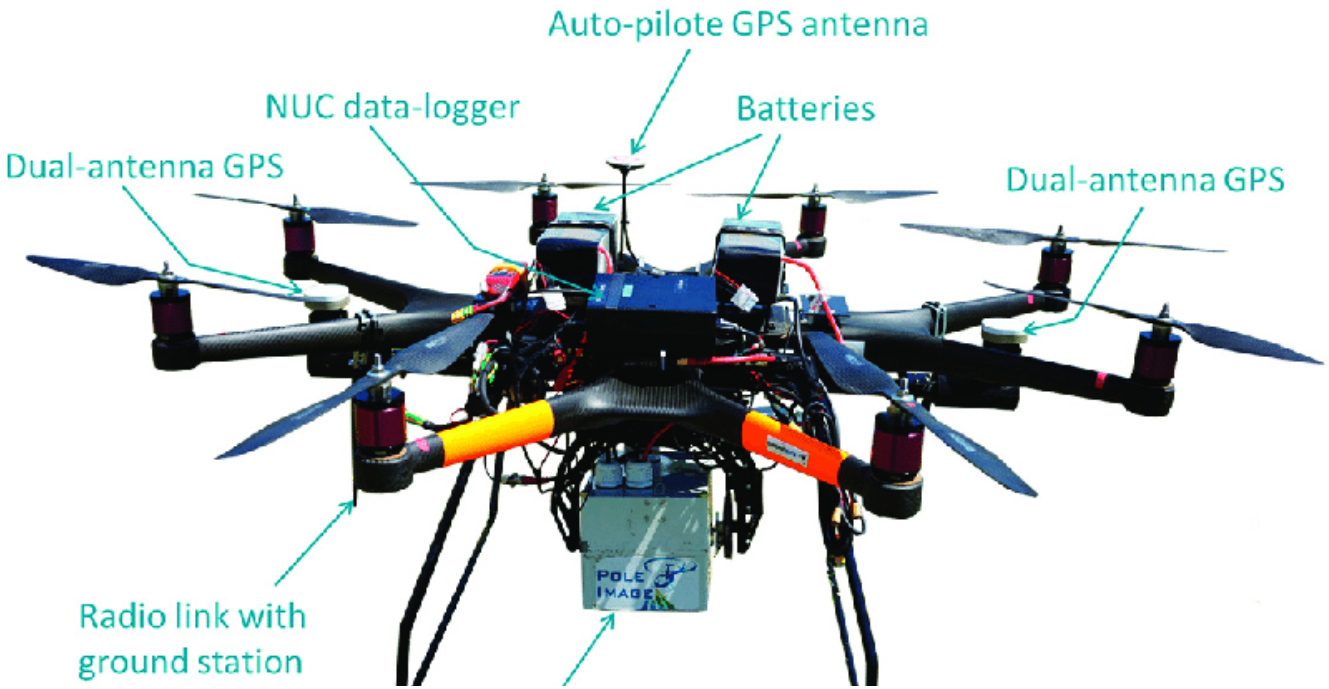
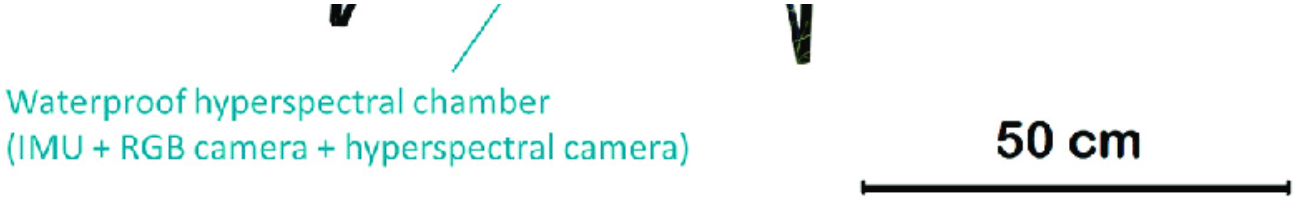
Drones has Many IMUs + GPS





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Why Monitor Flexible Structures?

- Alert Owner of Dramatic Movement of Bridge
- Twist, Sway and Motion Stress on Structure
- Slow Moving Oscillations - Coat Hanger Bending
- Prioritize Maintence After Extreme Weather
- Detect Permanent Deformations
- Insurance Benefits

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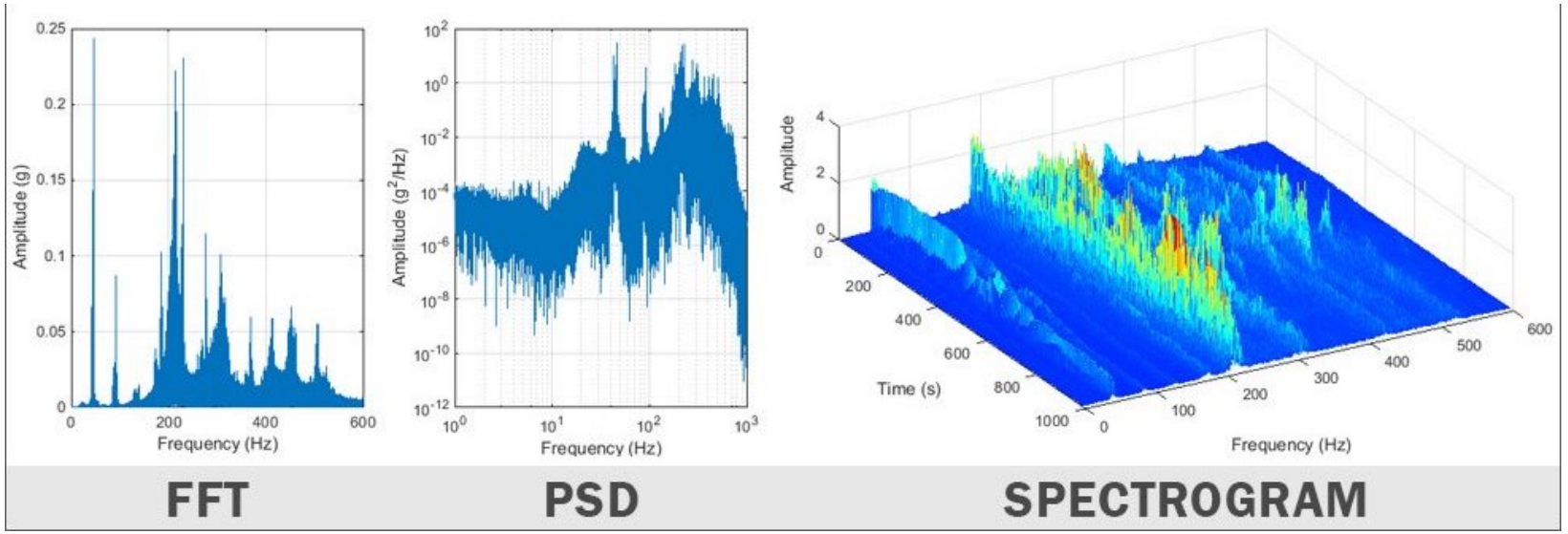
Modal Analysis and Movement Done with Fast Fourier Transform



Important - All Analysis Done on 1024 Sample Vectors !!

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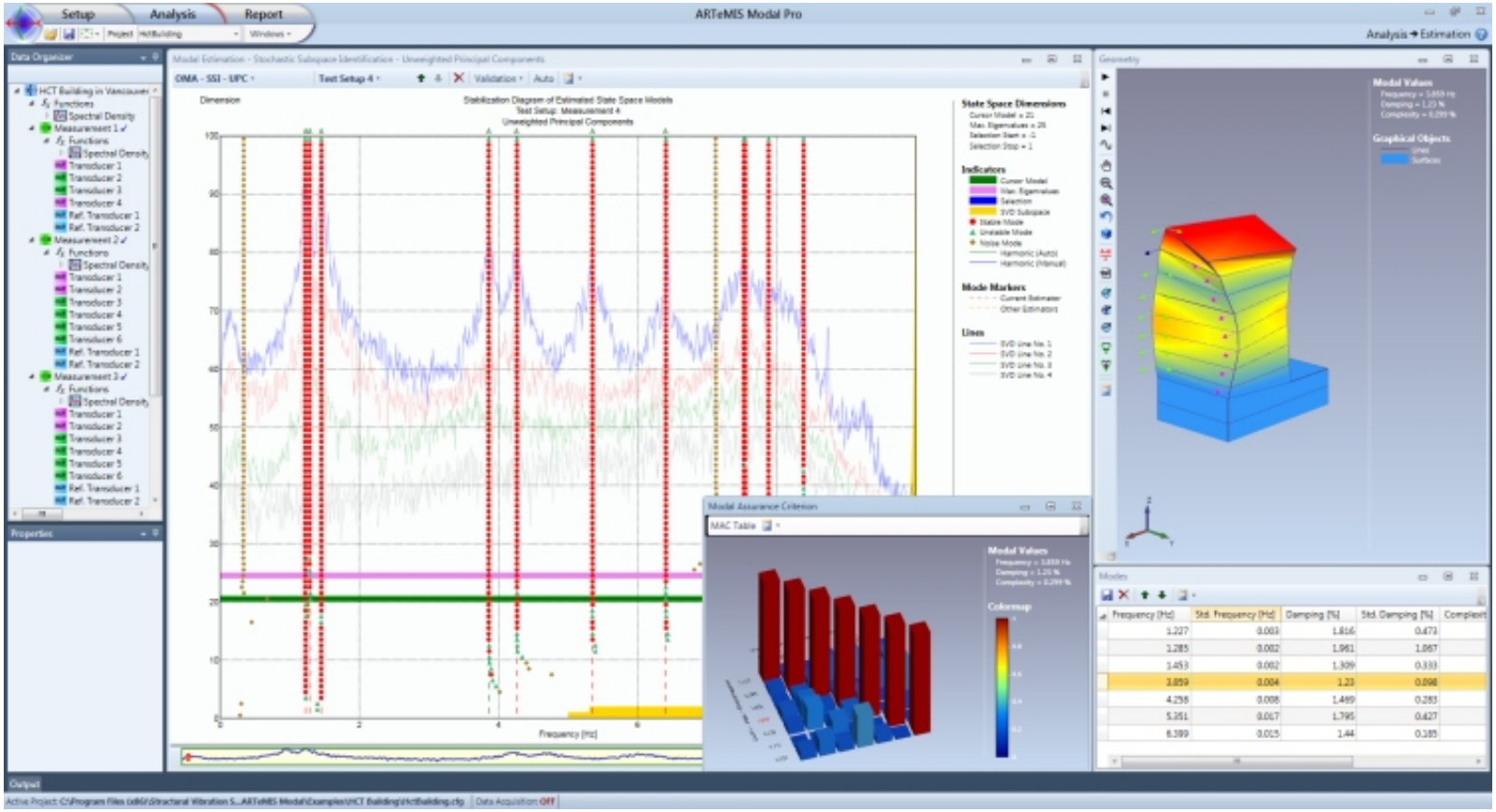
Bread and Butter of Vibrational/Modal Analysis



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Case Study - High Resolution Samples of 10 Vectors/Second/Sensor

- Our Customer is a Market Maker
- Oscillations up to 5 Times/Second (Nyquist Theorem)
- 1.5GB/month per sensor, uncompressed
- At Least Two Sensors per Structure

- At Least Two Sensors per Structure
- Speced to 100,000 sensors -> 145 TB/month, uncompressed

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YMR Samples Arrive from Bridge as a CSV File (via rsync)

```
sample_time yaw pitch roll ax ay az gx gy gz mx my mz

2017-10-08T05:46:49.171969067-05:00 -93.155 -4.702 1.571 -.775 -.259 -9.517 .000151 -.000056 -.000678 .0419 .2295 .4134
```

```
2017-10-08T05:46:49.268936247-05:00 -93.158 -4.703 1.570 -.777 -.252 -9.499 -.000214 .000166 -.000028 .0430 .2306 .4134

2017-10-08T05:46:49.371055098-05:00 -93.160 -4.703 1.569 -.794 -.248 -9.504 .001882 .001253 .000470 .0396 .2317 .4135

2017-10-08T05:46:49.473195095-05:00 -93.160 -4.701 1.571 -.774 -.254 -9.515 -.000170 -.000501 .000594 .0419 .2295 .4146

2017-10-08T05:46:49.568933484-05:00 -93.155 -4.704 1.567 -.794 -.249 -9.515 -.000689 -.000223 -.000024 .0431 .2340 .4160

...
```

1024 * 3 samples (rows) == 5.1min in single log segment, about 64kbytes

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Why Use PostgreSQL Instead of MongoDB/Spark?

- SQL Best for Complex Historical Patterns in Data
- PostgreSQL Easy to Extend to File Store for Samples (FDW)
- PostgreSQL Allow New Data Types - Vector Can be Hidden in File Store
- Materialized Views of MATLAB Calculations
- A/B Comparison (Profiles) of Motion and Mode Algorithms

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Vector Sample Log Table - bridge_log_vnymr_10hz

- Stores 5.1min @ 10hz == 3072 Tuples
- Key is Surrogate Sensor Id and Start Time for Each of 3, 1024 Segments
- Single PG Vector/Array for Sample Times
- Single PG Vector/Array for 12 Dimensional Floating Point Samples
- Compress Very Well

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SQL for Sample Times in Table bridge_log_vnymr_10hz

Table bridge_log_vnymr_10hz 20

SQL for 1024 * 3 * 12 YMR Samples in Table bridge_log_vnymr_10hz

Table bridge_log_vnymr_10hz 21

Vectors Compress Well but Tricky in SQL So Unpack with a View

```
CREATE VIEW vnymr_10hz_acc AS
  SELECT
        st.sensor_id,
        st.start_time,   ymr_st.sample_time,
        ymr_x.acc_x,     ymr_y.acc_y,       ymr_z.acc_z
    FROM
        tower_log_vnymr_10hz_sample_time st
          JOIN tower_log_vnymr_10hz_sensor sen ON (
                sen.sensor_id = st.sensor_id
                AND
```

```
        sen.start_time = st.log_start_time
)
JOIN tower_log_vnymr_10hz ymr ON (
        ymr.tower = sen.tower
        AND
        ymr.drop_id = sen.drop_id
        AND
        ymr.start_time = sen.start_time
)

--  sample time projection
JOIN LATERAL unnest(
        ymr.sample_time[st.sample_offset:st.sample_offset + 1023]
  ) WITH ORDINALITY AS ymr_st(sample_time, row) ON (
        TRUE
  )

--  x acceleration projection
JOIN LATERAL unnest(
        ymr.ymr[st.sample_offset:st.sample_offset + 1023][4:4]
  ) WITH ORDINALITY AS ymr_x(acc_x, row) ON (
        ymr_x.row = ymr_st.row
  )
```

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Unpacked View is Easy to Query

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Materialize Views Store MATLAB Results

```
/*
 *  X/Y/Twist/Sway/SwayAz Displacement by the VectorNav KF for VNYMR 10hz
 */
DROP TABLE IF EXISTS displace_vnkf_10hz CASCADE;
CREATE TABLE displace_vnkf_10hz
(
        sensor_id         sensor_id,
        profile           formal_name
                                REFERENCES vnymr_kalman_profile(name) ON DELETE CASCADE,
        start_time        timestamptz,

        x                       real[] CHECK (array_length(x, 1) = 1024),
        y                       real[] CHECK (array_length(y, 1) = 1024),
        twist                   real[] CHECK (array_length(twist, 1) = 1024),
        sway                    real[] CHECK (array_length(sway, 1) = 1024),
        swayaz                  real[] CHECK (array_length(swayaz, 1) = 1024),

        PRIMARY KEY       (sensor_id, profile, start_time),

        FOREIGN KEY       (sensor_id, start_time)
                          REFERENCES vnymr_10hz_order (
                                sensor_id,
                                start_time
                          ) ON DELETE CASCADE
);
```

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Vectors Can Reference Raw CSV Files Using Foreign Data Wrappers

- Use Custom Data Type - Can Not Override array[] (JavaScript has same problem)
- Vectors < 3 Months in PostgreSQL
- Vectors > 3 and < Year in CSV File
- Null Otherwise

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Storing Dense Vector Data Can be Done in PostgreSQL

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Thank you

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jmscott@setspace.com (mailto:jmscott@setspace.com)

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