

Advances In Wave Sensing Using MEMS

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The Internet of Things (IoT)...

- Worst acronym in history?
- The confluence of:
 - Readily available processing power and memory
 - Better sensors
 - Lower power consumption
 - Wireless communications
- Driving countless new applications



The Smartphone Principle

If it's used in smartphones (game controllers, smart cars, etc...) well-capitalized companies will invest vast sums to try to make it smaller, faster, more accurate, and power efficient.

How will land-based mass market IoT developments "spill over" and enable the internet of floating/underwater things?



Some Problems measuring waves...

How accurate is accurate enough?
Small inaccuracies can integrate into big errors...

 Operational versus Scientific: Tradeoff between manipulating/consolidating data on-buoy for easy transmission versus thorough retrospective analysis of complete data set...



Some Solutions...

- Focus on wave stats rather than absolute values
- Work in frequency domain
 - It's where you go for many of the relevant representational wave statistics anyway...
 - Apply filters such as mean removal or noise removal (Lang 1987) to improve accuracy

Add processing power on-buoy...

- Opens possibilities for improved assessment/data manipulation/correction
- New data manipulation innovations?



An early MEMS Wave sensor (SVS-602)





Early sensors showed this approach works

- Deployed in both Great Lakes and near shore ocean environments
- Compares well with reference sensor



Sept. 1, 2011 - Oct. 5, 2011: Dominant Period Comparison



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Reference: Brown and Meadows, 2011

But Technology Marches Forward...

- Better sensor accuracy/more outputs
- Less power consumption
- More/cheaper processing power/memory
- Flash memory price/size drop: Now practical to include raw data logging onboard...
- Temperature compensation/other accuracy features
- New possibilities...



SeaView's SVS-603





SVS-603 Features

- 14 bit sensors with full x, y, z acceleration, pitch, roll, heading, angular velocity, and magnetometer output
- Powerful on-board CPU
- Highly configurable: Serial and USB ports with separately controlled summary or detailed data streams
- On-board micro-SD card with configurable data stream
- Smaller/Lower power (130mW!)/System clock/etc...
- Dedicated GUI/Full set of algorithms



The SVS-603...



File View Setup Orientation UTC Time: 1 LPF Cutoff: 2 Offset Z: 0 Declination Angle: 0 Timestep interval: 1	n Acceleration FFT 16:51:24 10/16/2016 20.00				
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Buoy motion non-idealities

- Pitch and roll perturb motion
 - Shifting to earth frame gets motion of interest
- Position away from roll center perturbs motion
 - Fortunately if the motion of a sensor that is a fixed displacement away from the roll center is known, the motion of the roll center can be readily determined using outputs from newer sensors
 - Angular velocity (available from sensor)
 - Angular acceleration (easily calculated)
- Thanks to the aircraft applications these algorithms are well documented...



Thank you rocket scientists!

The inverse relationships are

- $p = \dot{\phi}_{g} \dot{\psi}_{g} \sin \theta_{g} \dot{L} \cos \theta_{g} \cos \psi_{g} (\Omega_{e} + \dot{\lambda})(\cos L \cos \theta_{g} \sin \psi_{g} \sin L \sin \theta_{g})$
- $\mathbf{q} = \dot{\theta}_{g} \cos \phi_{g} + \dot{\psi}_{g} \sin \phi_{g} \cos \theta_{g} \dot{\mathbf{L}} \left(\sin \theta_{g} \cos \psi_{g} \sin \phi_{g} \sin \psi_{g} \cos \phi_{g} \right)$
 - $(\Omega_{e} + \dot{\lambda}) \cos L(\sin \theta_{g} \sin \psi_{g} \sin \phi_{g} + \cos \psi_{g} \cos \phi_{g})$
 - $(\Omega_e + \dot{\lambda}) \sin L \sin \phi_g \cos \theta_g$
- $\mathbf{r} = -\dot{\theta}_{g} \sin \phi_{g} + \dot{\psi}_{g} \cos \phi_{g} \cos \theta_{g} \dot{\mathbf{L}} \left(\sin \theta_{g} \cos \psi_{g} \cos \phi_{g} + \sin \psi_{g} \sin \phi_{g} \right)$
 - $(\Omega_e + \dot{\lambda}) \cos L(\sin \theta_g \sin \psi_g \cos \phi_g \cos \psi_g \sin \phi_g)$
 - $(\Omega_{\rm e} + \dot{\lambda}) \sin L \cos \phi_{\rm g} \cos \theta_{\rm g}$

Vehicle Coordinates

Vehicle coordinates can be computed from the X,Y,Z axes velocity components and vehicle Euler angles by integrating the equations

$$\begin{split} \dot{\mathbf{x}}_{g} &= \mathbf{u} \, \cos \, \psi_{g} \, \cos \, \theta_{g} + \mathbf{v} \left(\cos \, \psi_{g} \, \sin \, \theta_{g} \, \sin \, \phi_{g} \, - \, \sin \, \psi_{g} \, \cos \, \phi_{g} \right) \\ &+ \mathbf{w} \left(\cos \, \psi_{g} \, \sin \, \theta_{g} \, \cos \, \phi_{g} + \, \sin \, \psi_{g} \, \sin \, \phi_{g} \right) \\ \dot{\mathbf{y}}_{g} &= \mathbf{u} \, \sin \, \psi_{g} \, \cos \, \theta_{g} + \mathbf{v} \left(\sin \, \psi_{g} \, \sin \, \theta_{g} \, \sin \, \phi_{g} + \, \cos \, \psi_{g} \, \cos \, \phi_{g} \right) \\ &+ \mathbf{w} \left(\sin \, \psi_{g} \, \sin \, \theta_{g} \, \cos \, \phi_{g} \, - \, \cos \, \psi_{g} \, \sin \, \phi_{g} \right) \\ \cdot \end{split}$$
(V-13)

(V-15)

(V-16)

 $\dot{z}_g = -u \sin \theta_g + v \cos \theta_g \sin \phi_g + w \cos \theta_g \cos \phi_g$

$$r_g = \sqrt{x_g^2 + y_g^2 + z_g^2}$$







New Zealand (Cawthron Institute) deployment



Hs comparison (New Zealand)



— Hs (SVS-603) — Hs (Triaxys 170) — Hs (Triaxys 090)

Data courtesy of Cawthron Institute



Hs comparison (New Zealand)



— Hs (SVS-603) — Hs (Triaxys 6922) — Hs (Triaxys 170) — Hs (Triaxys 090)

Data courtesy of Cawthron Institute



Dominant Period comparison (New Zealand)



Data courtesy of Cawthron Institute



Hs comparison: Southern French coast (1.2 m above roll center)



Data courtesy of Mobilis SA



Period comparison: Southern French coast (1.2 m above roll center)



Data courtesy of Mobilis SA



Hs comparison: Great Lakes deployment



Data courtesy of Limnotech



Measured Wave Height Comparison

Why a dedicated GUI?

- Convenience
- Dedicated graphical standard plots...
- Easily backtest new algorithms
- Apply and assess RAO functions
- Web interface?
- Specialty applications?

With great power comes great responsibility...



Ongoing work...

Test on a wider range of buoy hulls Develop methodology for fitting buoy hull response based on comparison data Configurable RAO function Explore algorithm improvements for non-ideal hulls/mounting position/buoy pitch/roll Other enhancements for specialized applications

- Scheduler
- Triggering events
- More TBD...



Thank you!

Please contact me to find out more or explore how we can support your application!

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