DYNAMIC POSITIONING CONFERENCE
October 11-12 2016

LUNCH PRESENTATION

The Cybernetics of Dynamic Positioning in an Historic Perspective

Nils Albert Jenssen

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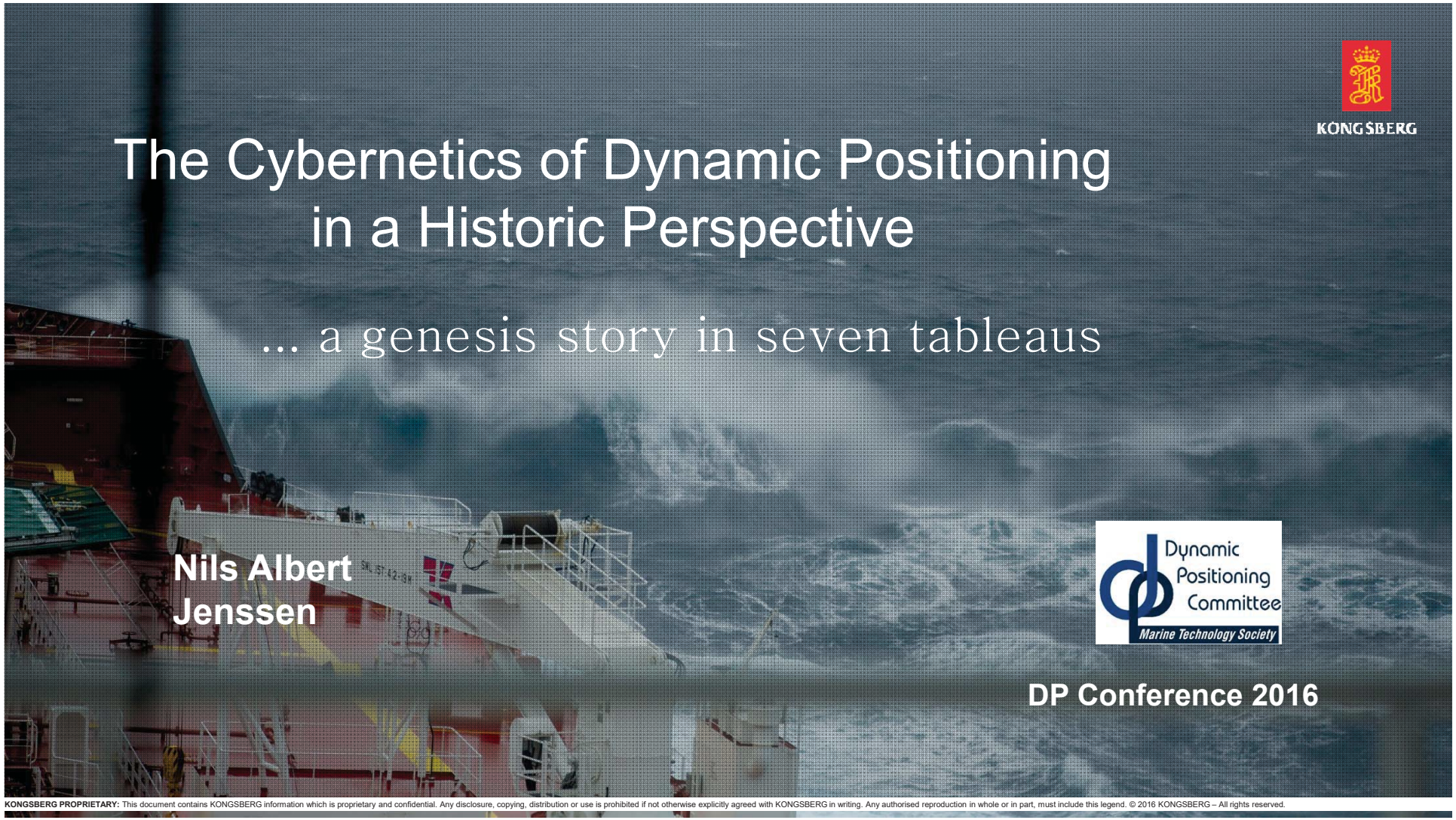

The Cybernetics of Dynamic Positioning in a Historic Perspective

… a genesis story in seven tableaus

Nils Albert Jenssen

KONGSBERG

Dynamic Positioning Committee
Marine Technology Society

DP Conference 2016

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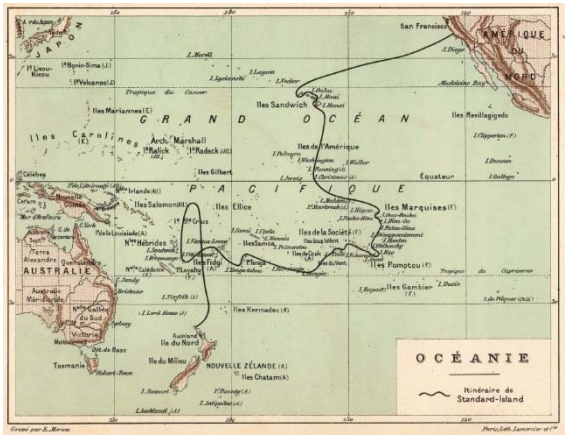
Prior art

- Conceptual idea of DP published 1895
- Novel: Jules Verne - The Propeller Island
  - String quartet traveling from San Francisco to San Diego
  - Ended up on the floating Standard-Island
  - Propellers kept position (steady as an island)
  - Too deep for mooring



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The genesis

The first day of creation (1960)

CUSS 1

CUSS:

Continental, **U**nion, **S**hell & **S**uperior oil consortium

Core drilling

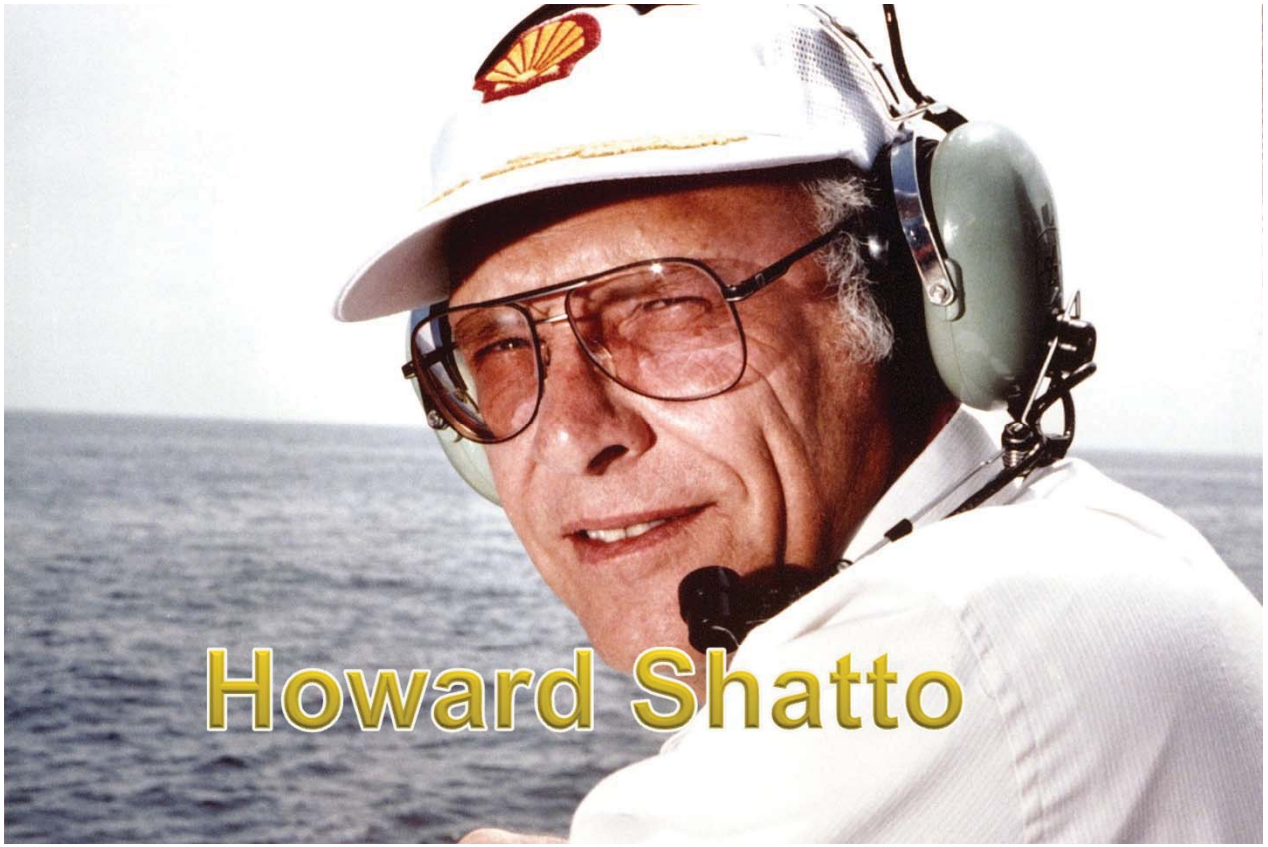
- Goal ±180 m
- Water depth up to 3500m

Equipment

- Four azimuth thrusters
- Manual control

- Visual observations
- Sonar tracking

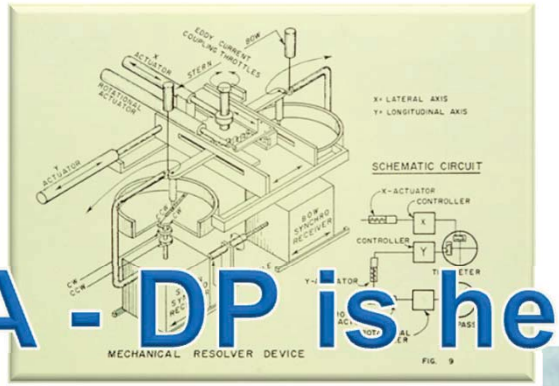
We all know this man!



The invention

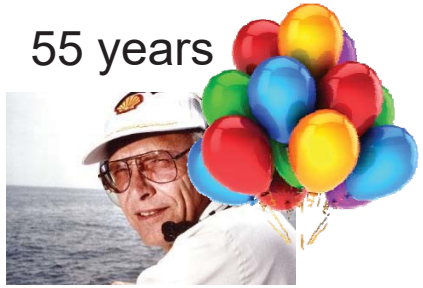
The second day of creation (1961)

EUREKA - DP is here



The Eureka

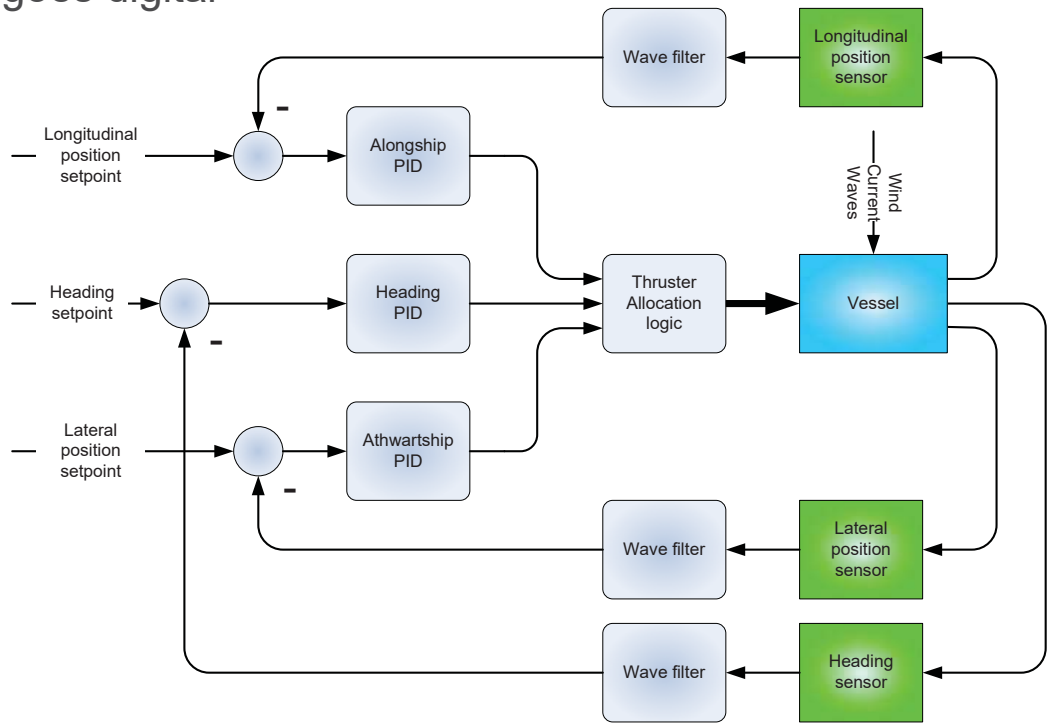
55 years

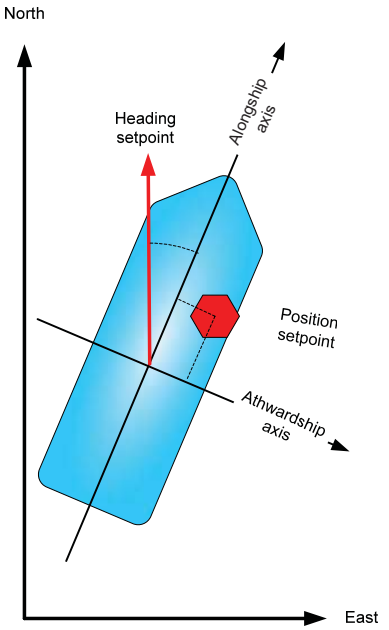


The commerce starts

The third day of creation - 1967

- DP goes digital



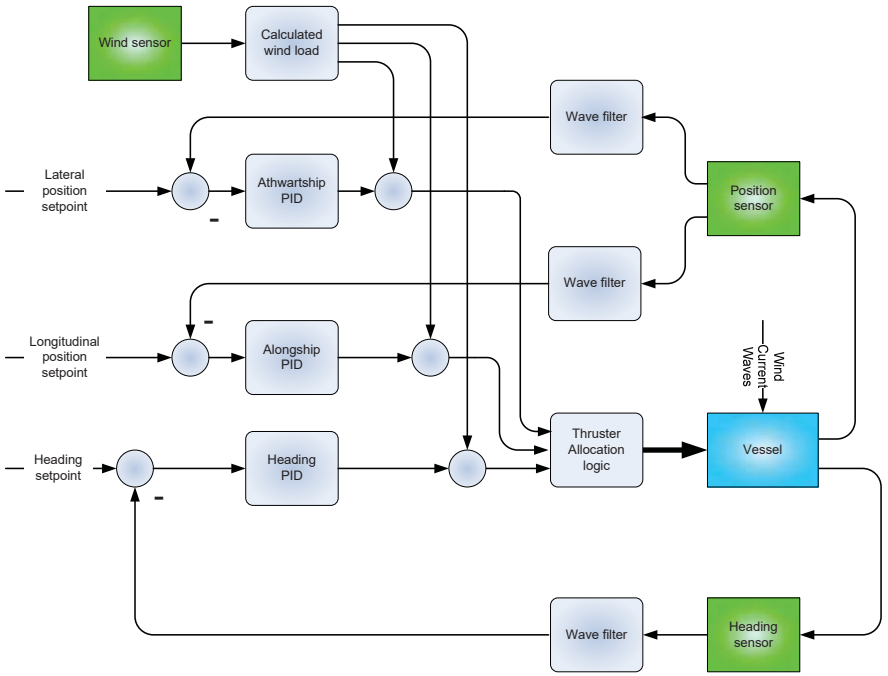


Glomar Challenger

The first de facto industry standard

The fourth day of creation (1971)

- Classic control theory as before
- Wind feed forward



- Computer redundancy
- Sensor redundancy
  - Acoustics (Short Base Line)
  - Taut wire
  - Riser angle

DP comes to Norway

The fifth day of creation (1970 – 75)

- Prof. Jens G Balchen (NTNU) – visiting professor at UCSB (1968-69)
  - Norway large maritime history
  - New unsurpassed solution based on “Modern control theory”
- No commercial interest
- Kongsberg contract with Stolt-Nielsen 1975
- First DP operation 17. May 1977

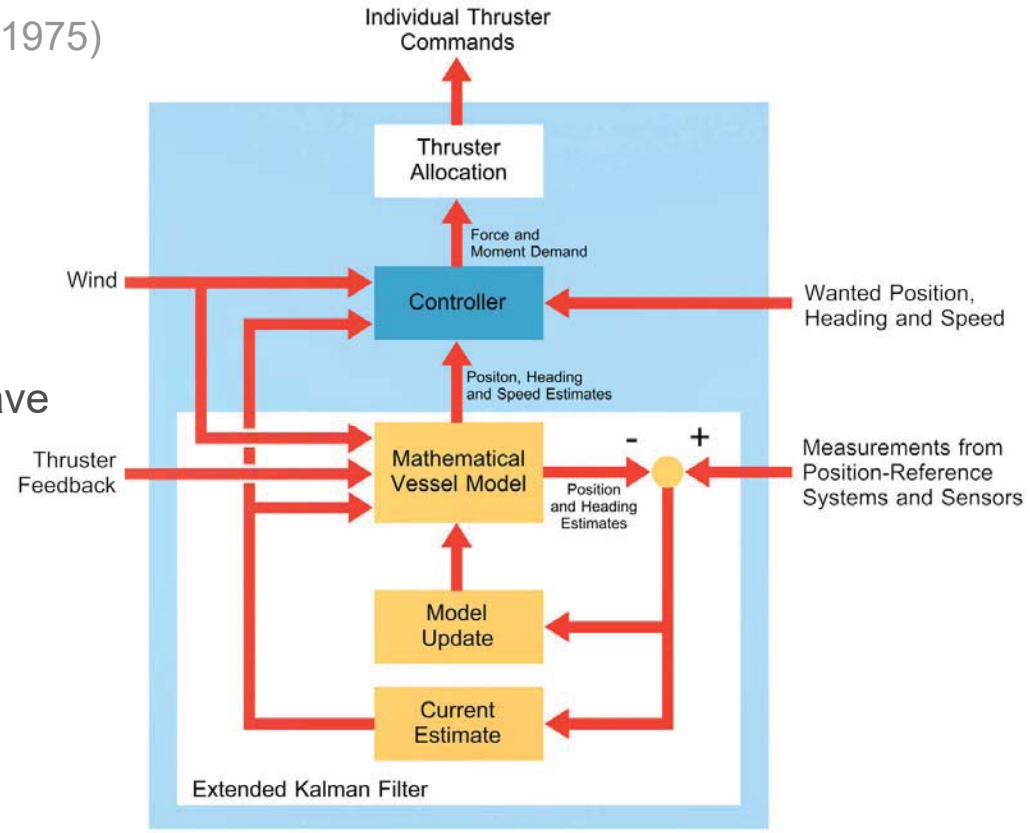
Seaway Eagle

Seaway Swan

The new dawn

The sixth day of creation – sun rise (1975)

- Modern control theory
  - Model based
  - Multivariable control
  - Optimal control
  - Kalman filter with adaptive wave filtering

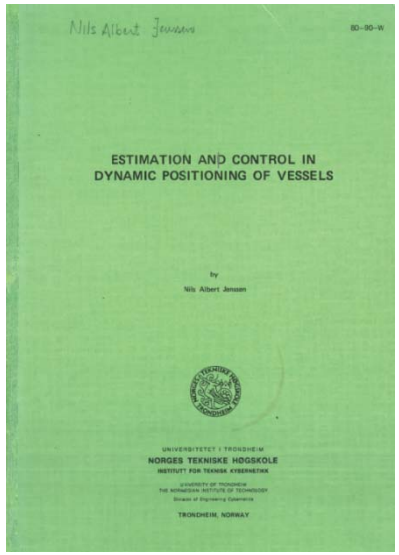


The optimal control

The sixth day of creation – morning (1976 – 80)

- Mathematical model of the process
- Linear theory
- All states not available by measurements – hence State Estimator
- Principle of separation (Linear systems only)
  - state estimation
  - linear quadratic optimal control based on estimator model

- **SORRY! - Not linear system at all**
  - **Approximations**
  - **Transformations**
  - **Make it rather linear**



$$S = \begin{bmatrix} \cos\psi & \sin\psi \\ -\sin\psi & \cos\psi \end{bmatrix}$$

The data fusion

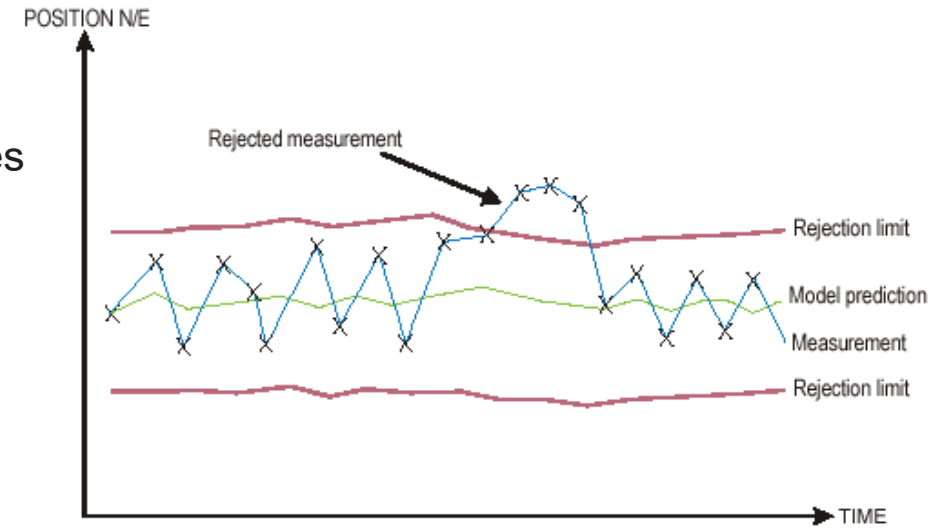
The day of creation – morning (1976 - 80)

Standard approach:

- Select which reference system through prioritising
- At failure switch to next on list

The new way:

- Use all available systems at all times
- Optimal statistical mix
- Improved detection of spurious measurements
  - Test against predicted motion



The revelation

The sixth day of creation – morning (1980)

MODELING, IDENTIFICATION AND CONTROL, 1980, VOL. 1, NO. 3, 135–163
doi:10.4173/mic.1980.3.1

A dynamic positioning system based on Kalman filtering and optimal control

JENS G. BALCHEN†, NILS A. JENSSEN‡, ELDAR MATHISEN§ and STEINAR SÆLID†

Keywords: *dynamic positioning*, *Kalman filtering*, *optimal control*.

This paper describes a computer-based, dynamic positioning system for floating vessels. The system is based on a detailed mathematical model of vessel motion in

The Monday morning blues

The sixth day of creation – morning (1976 – 80)

- Mini computers too slow to implement Kalman filter according to text book

- SIMPLIFICATION
  - The art of engineering
- Kalman filter became a must
  - All competitors followed
  - Few knew what it was
  - Very different implementations
- Achievements (selling points):
  - More precise contr
  - Better noise filt ring
  - Less thruster wear and tear
  - Survive without measurement for a short period

New industry standard DP established

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At least somebody had confidence in the advances

(he was not even payed)

The world starts getting spherical

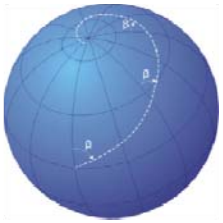
The sixth day of creation – noon (1990 - 95)

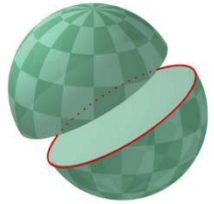
- Increased navigational requirements
  - Cruise liners
  - Long distance cable laying
  - North Sea UTM world gets insufficient
    - Straight UTM line is curved on Earth
    - Loxodrome or Great circle is a funny curve on UTM map

UTM: 60 zones (Cartesian)

Loxodrome (Rumb line): Line with fixed direction

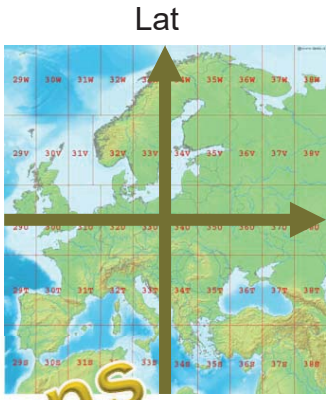
Great circle: Shortest distance





The world is nearly spherical

The sixth day of creation – noon (1990 - 95)



Calculating UTM (*N, E*) from Lat/Lon (λ, φ):

- Datum WGS 84 (GPS), ED 50 (North Sea)
- Earth is an oblate spheroid
  - radius of a = 6378.137 km
  - inverse flattening of 1/f = 298.257223563
  - northern hemisphere N_0 = 0 km, southern hemisphere N_0 = 10 000 km
  - k_0 = 0.9996 and E_0 = 500 km
  - reference meridian λ_0

NB: Simplified equations

$$E = E_0 + k_0 A \left(\eta' + \sum_{j=1}^{3} \alpha_j \cos(2j\xi') \sinh(2j\eta') \right)$$

$$N = N_0 + k_0 A \left(\xi' + \sum_{j=1}^{3} \alpha_j \sin(2j\xi') \cosh(2j\eta') \right)$$

where $t = \sinh\left(\tanh^{-1} \sin\varphi - \frac{2\sqrt{n}}{1+n} \tanh^{-1}\left(\frac{2\sqrt{n}}{1+n} \sin\varphi \right) \right)$, $\quad n = \frac{f}{2-f}$, $\quad A = \frac{a}{1+n}\left(1 + \frac{n^2}{4} + \frac{n^4}{64} + \cdots\right)$,

$$\xi' = \tan^{-1}\left(\frac{t}{\cos(\lambda - \lambda_0)} \right), \quad \eta' = \tanh^{-1}\left(\frac{\sin(\lambda - \lambda_0)}{\sqrt{1+t^2}} \right), \quad \alpha_1 = \frac{1}{2}n - \frac{2}{3}n^2 + \frac{5}{16}n^3, \quad \alpha_2 = \frac{13}{48}n^2 - \frac{3}{5}n^3, \quad \alpha_3 = \frac{61}{240}n^3,$$

The world is spherical

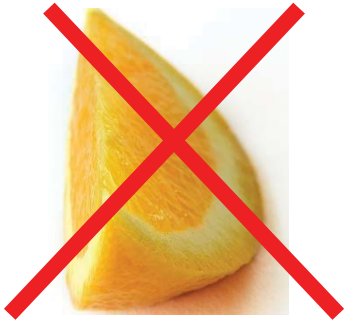
The day of creation – afternoon (1995 - 98)

- The only solution - model the vessel motion on the curved surface
  - Position Lat / Lon angular coordinates (λ, φ)
  - Velocities in vessel coordinates
  - Nonlinearities are manageable
- Position offsets (δλ, δφ) in controller converted to distances
- Tough computational load

Free at last from UTM nightmare

BENEFITS

- Works everywhere – easier to operate
- Long distance problem solved
- Support for all kinds of geodetic datum



Kalman in full swing

The sixth day of creation – afternoon (1995 - 98)

- Full implementation of Extended Kalman filter
- Improved reference system handling
  - Data quality (geometry and signal quality - error ellipses)
  - Data rates
  - Mathematical model uncertainty

Correction:

$$\varepsilon_k = y_k - D\bar{x}_k$$

$$K_k = \bar{P}_k D^T (D\bar{P}_k D^T - W)^{-1}$$

$$\hat{x}_k = \bar{x}_k + K_k \varepsilon_k$$

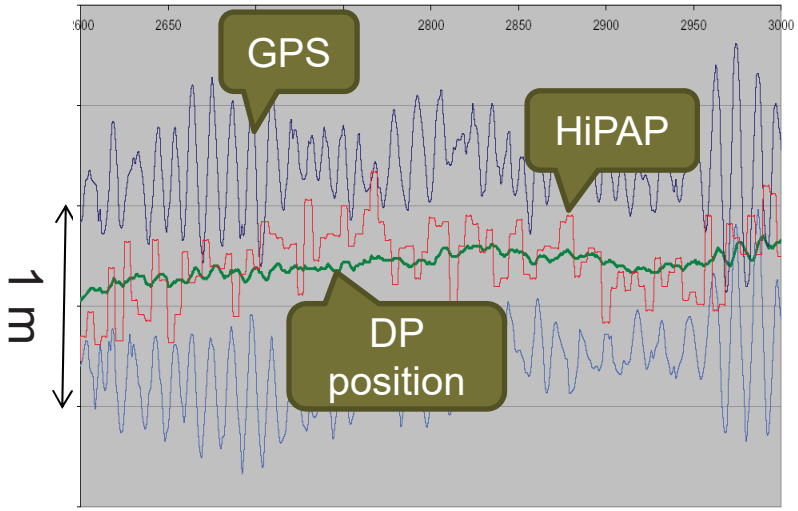
$$\hat{P}_k = (I - K_k D)\bar{P}_k (I - K_k D)^T + K_k W K_k^T$$

Prediction:

$$\bar{x}_{k+1} = f(\hat{x}_k, u_k)$$

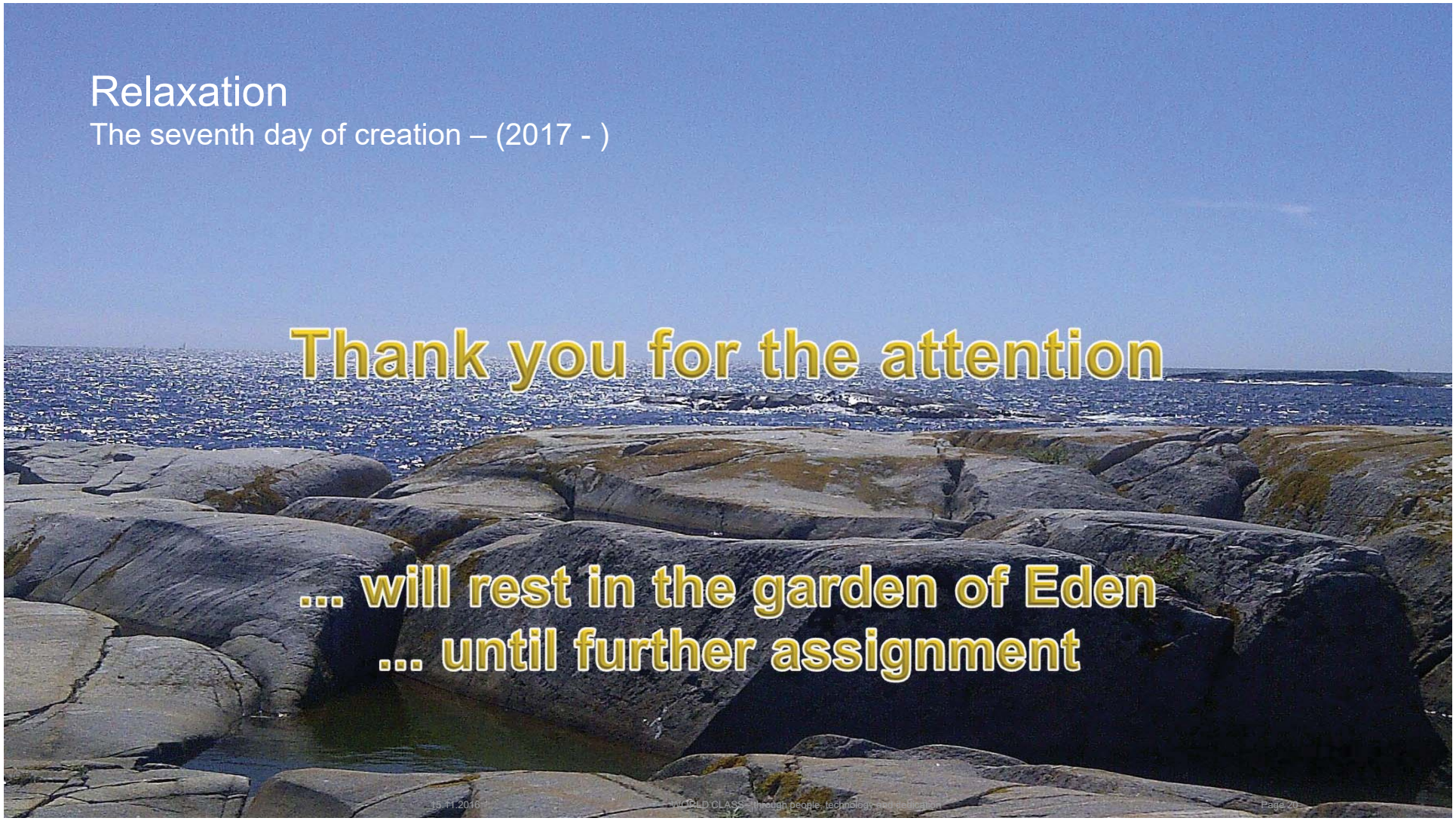
$$\bar{P}_{k+1} = \Phi \hat{P}_k \Phi^T - V_k$$

$$\Phi = df/dx$$



Solving the new challenges

The sixth day of creation – evening (2016 -)

Relaxation

The seventh day of creation – (2017 -)