Nanyang Technological University

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Neural Network Based Orbit Propagation for Small Satellite Missions

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Objective

- Design an Artificial Neural Network (ANN) based orbit predictor.
- Investigate the feasibility of ANN as back-up to GPS receiver failures / outages.

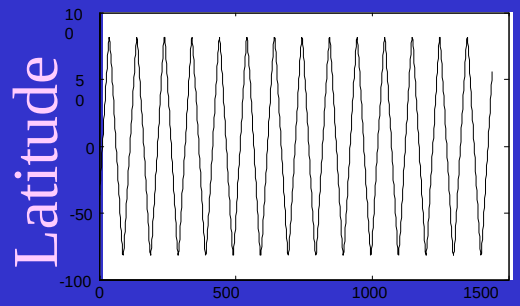
Contents

- Characterization of the orbital motion in terms of geodetic parameters
- Artificial Neural Network design
- ANN based onboard orbit prediction as back-up for in GPS receiver
- Simulation results
- Conclusion

Small Satellite Program at NTU

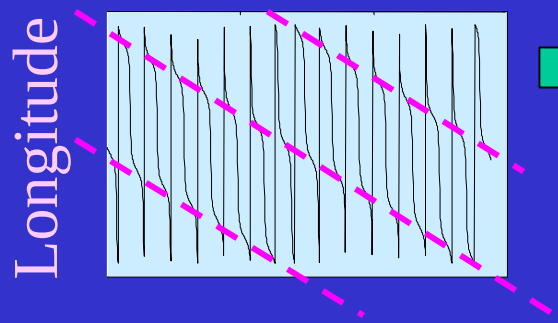
- Mission
  - Remote Sensing
  - Data, Message Communications
  - Software Payload using Parallel Processing Units
- Orbit
  - Sun Synchronous Orbit (Altitude 620 ~ 820 Kms depending upon the primary satellite
- Payloads
  - IRIS Camera (10 m GSD, 50Km swath)
  - ADAM Payload (communications)
  - PPU (Software Payload)
- ADCS
  - Magnetometer, Sun sensor, Star Tracker, Rate Sensor
  - Reaction Wheels, Magnetic Torquers

Characterization



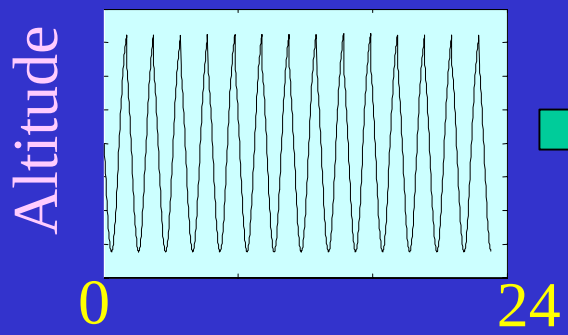
Cyclic

$$\phi_t = \phi(T + \tau)$$



Cyclic superimposed with secular component

$$\lambda_t = \lambda_0 - N \bullet \Delta\lambda_{avg} + \delta\lambda(T + \tau)$$



Cyclic

$$h_\tau = h(T + \tau)$$

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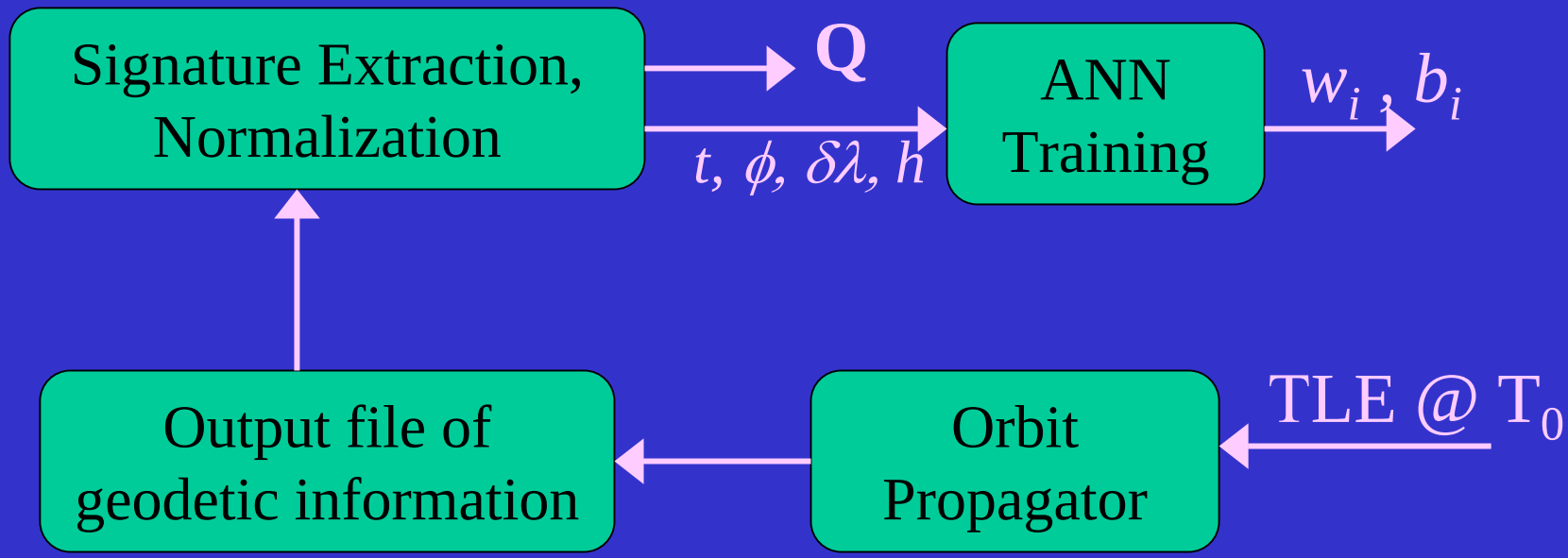
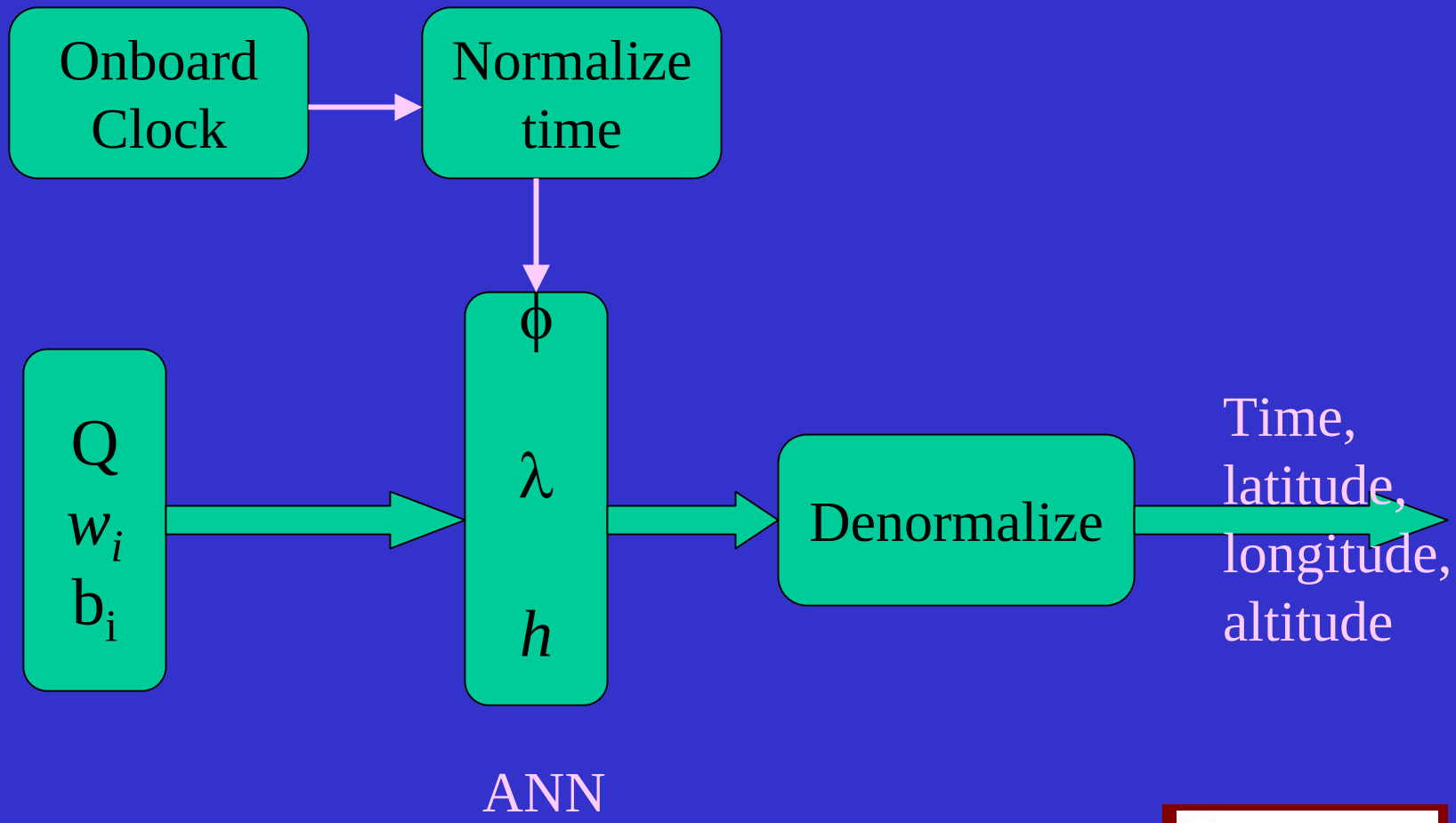
Proposed Strategy for ANN



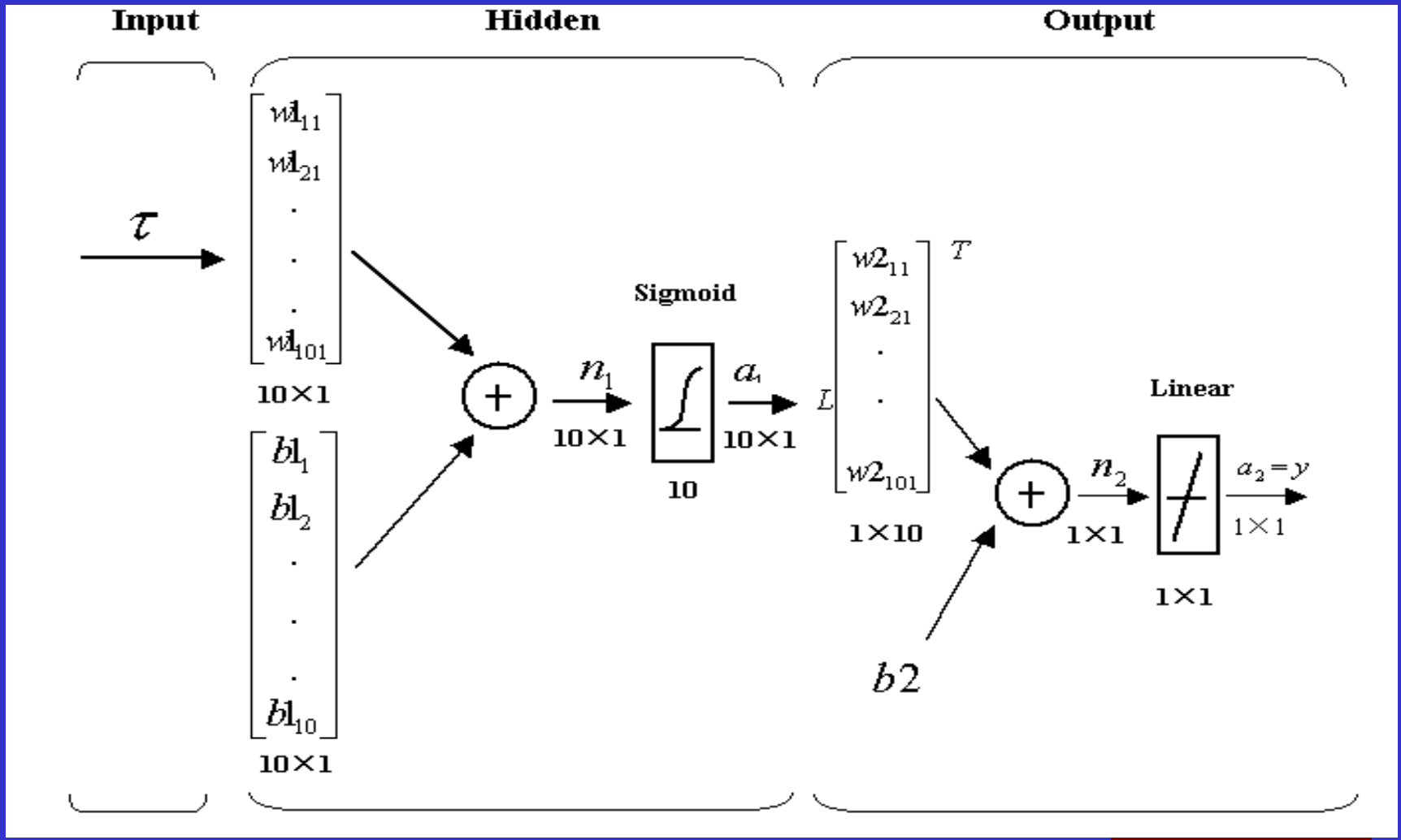
Q = T_{avg}, $\Delta\lambda$, λ_0, min, max values of time, latitude, longitude, altitude used in normalization.

Q, w_i , b_i *are to be up-linked to the satellite*

Onboard Orbit Prediction by ANN



Typical 3 Layer Network



ANN Results

Satellite Name	Inclination (degree)	Net ID	Neuron Number (N)	SSE	Number of parameters (p)	Minimum Error (deg)	Maximum Error (deg)	STD of Errors (deg)
ADEOS	98.4284	Net1	10	3.687e-5	26	-0.1634	0.1857	0.0538
		Net2	7	9.981e-6	21	-0.2492	0.2315	0.0660
OKEAN4	82.5406	Net1	10	3.634e-5	26	-0.1561	0.1929	0.0604
		Net2	9	1.414e-5	24	-0.4961	0.1677	0.0775
K023	66.0808	Net1	8	2.068e-5	20	-0.1153	0.1267	0.0590
		Net2	8	9.563e-6	21	-0.0847	0.2730	0.0650
ISS	51.5901	Net1	7	2.482e-5	17	-0.1272	0.1158	0.0394
		Net2	5	7.306e-6	13	-0.1037	0.3461	0.0754
ROCSAT1	34.9826	Net1	6	4.574e-5	14	-0.0768	0.1427	0.0420
		Net2	5	2.708e-6	13	-0.1615	0.1375	0.0613
P034	28.4627	Net1	5	9.002e-5	14	-0.1118	0.0832	0.0392
		Net2	5	2.853e-6	14	-0.1335	0.0584	0.0364

Net1: Latitude network; Net2: Longitude Network ; $p < 3N+1$ as decided by the Matlab training function TRAINBR

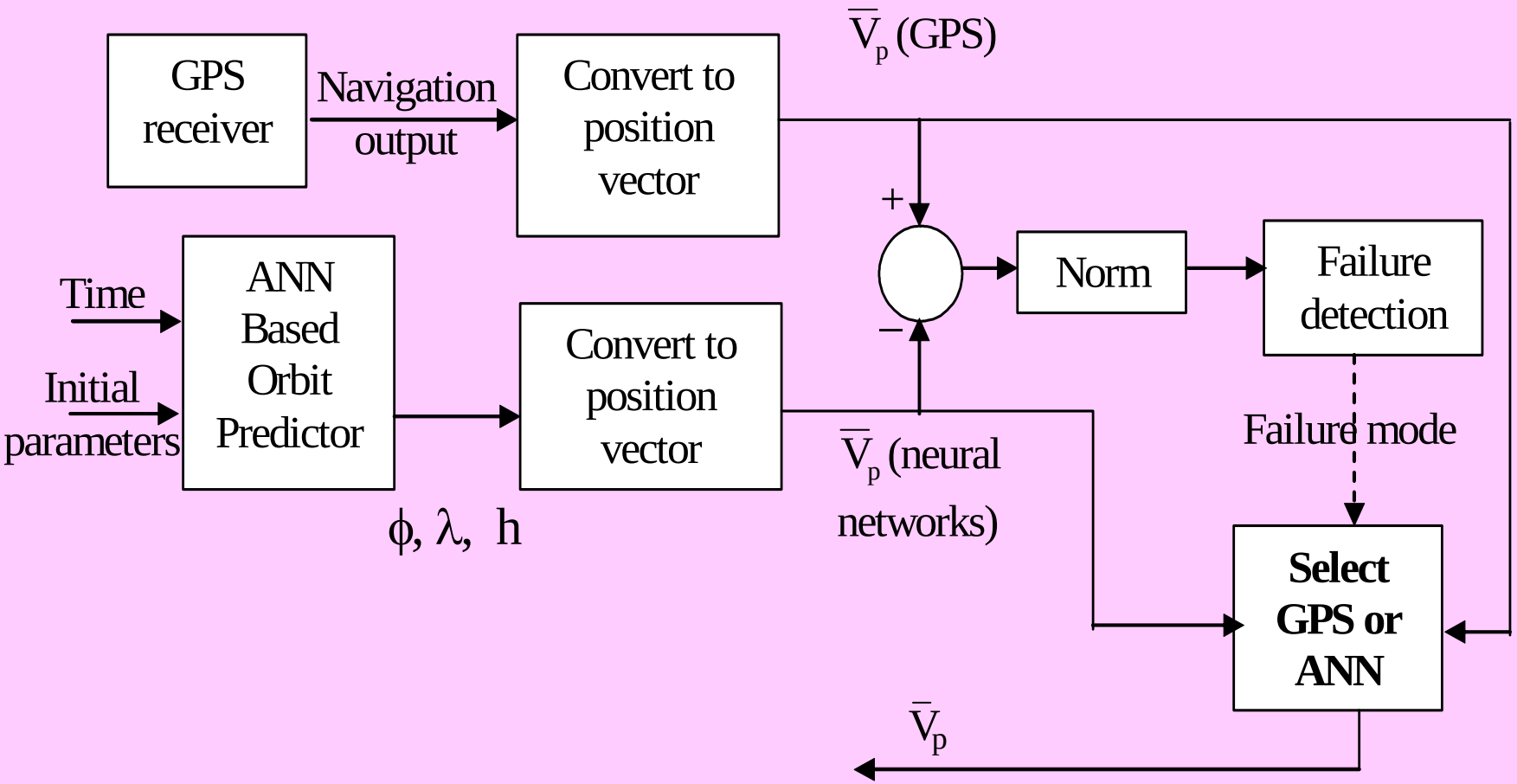
Requirement for Failure Detection

- During normal phase onboard orbit information is provided by GPS Receiver.
- GPS Data outage can occur due to
  - Sun Tracking during non-imaging periods
  - Large slew maneuvers

It is therefore required to provide back-up to GPS Receiver during outages…..

Can the ANN provide back-up support ?

Proposal for Failure Detection

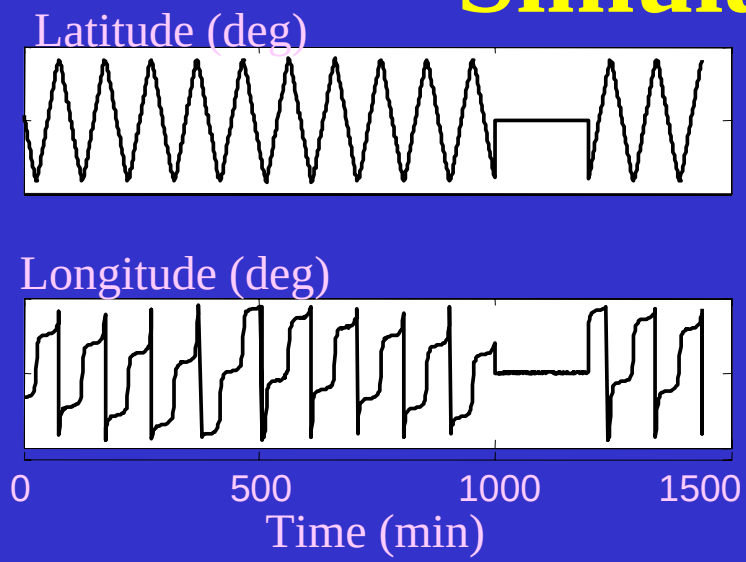


Failure Detection Strategy

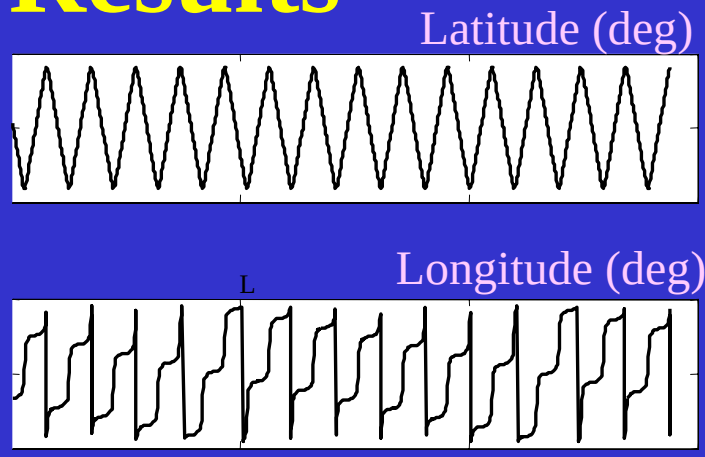
1. Form the position vectors (V_p) from the output of GPS Rx and the ANN network.
2. Calculate the norm of the difference in position vectors
3. Calculate the variance of the difference based on finite window size (say 4 consecutive samples)
4. Use the variance to detect the failure mode (*normal*, *increased noise*, or *total failure*)
5. Check with the norm of the difference (step-2) for consistency

$$\mathbf{V}_p = (r_e + h) * \begin{bmatrix} \cos\phi \cdot \cos\lambda \\ \cos\phi \cdot \sin\lambda \\ \sin\phi \end{bmatrix}$$

Simulation Results



GPS Output

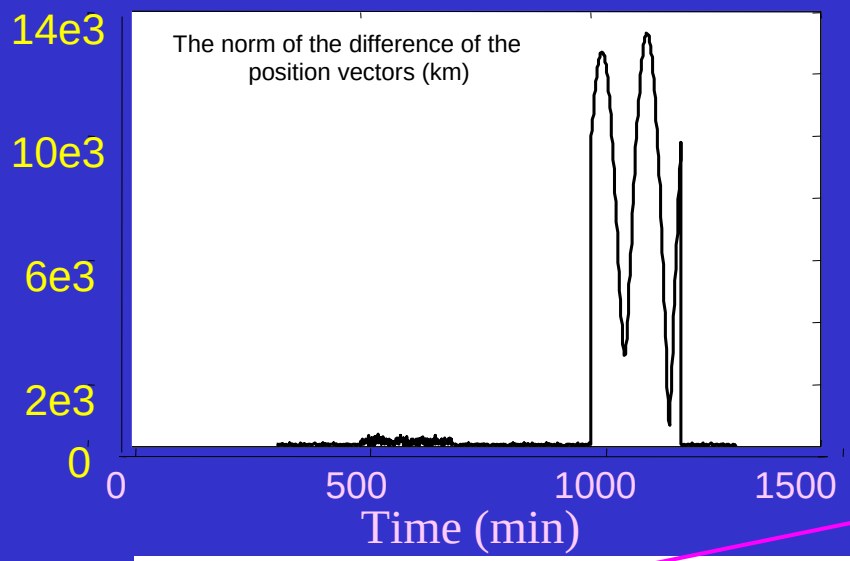


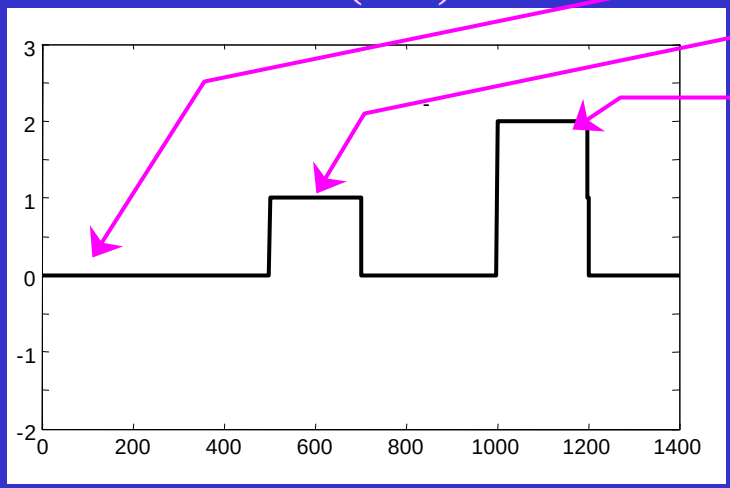
ANN Output

Failure Modes in GPS Output

- 500 – 700 ‘Increased noise mode’
- 1000-1200 ‘Total Failure (no signal) mode
- Otherwise ‘Normal’

Simulation Results

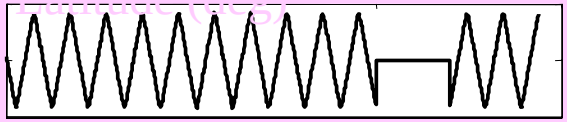




Flag
0 = normal;
1 = increased noise;
2 = total failure

Failure Mode Detection

Simulation Results



GPS receiver

Navigation output

Convert to position vector

$\bar{V}_p$ (GPS)

+

−

Norm

Failure detection

Time

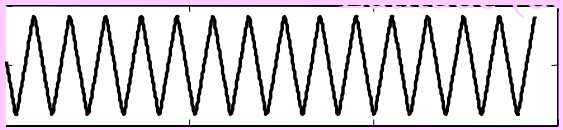
Initial parameters

ANN Based Orbit Predictor

Convert to position vector

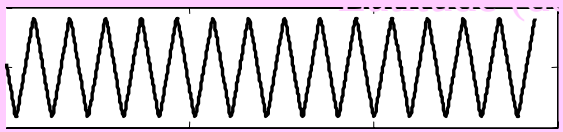
$\bar{V}_p$ (neural networks)

Failure mode

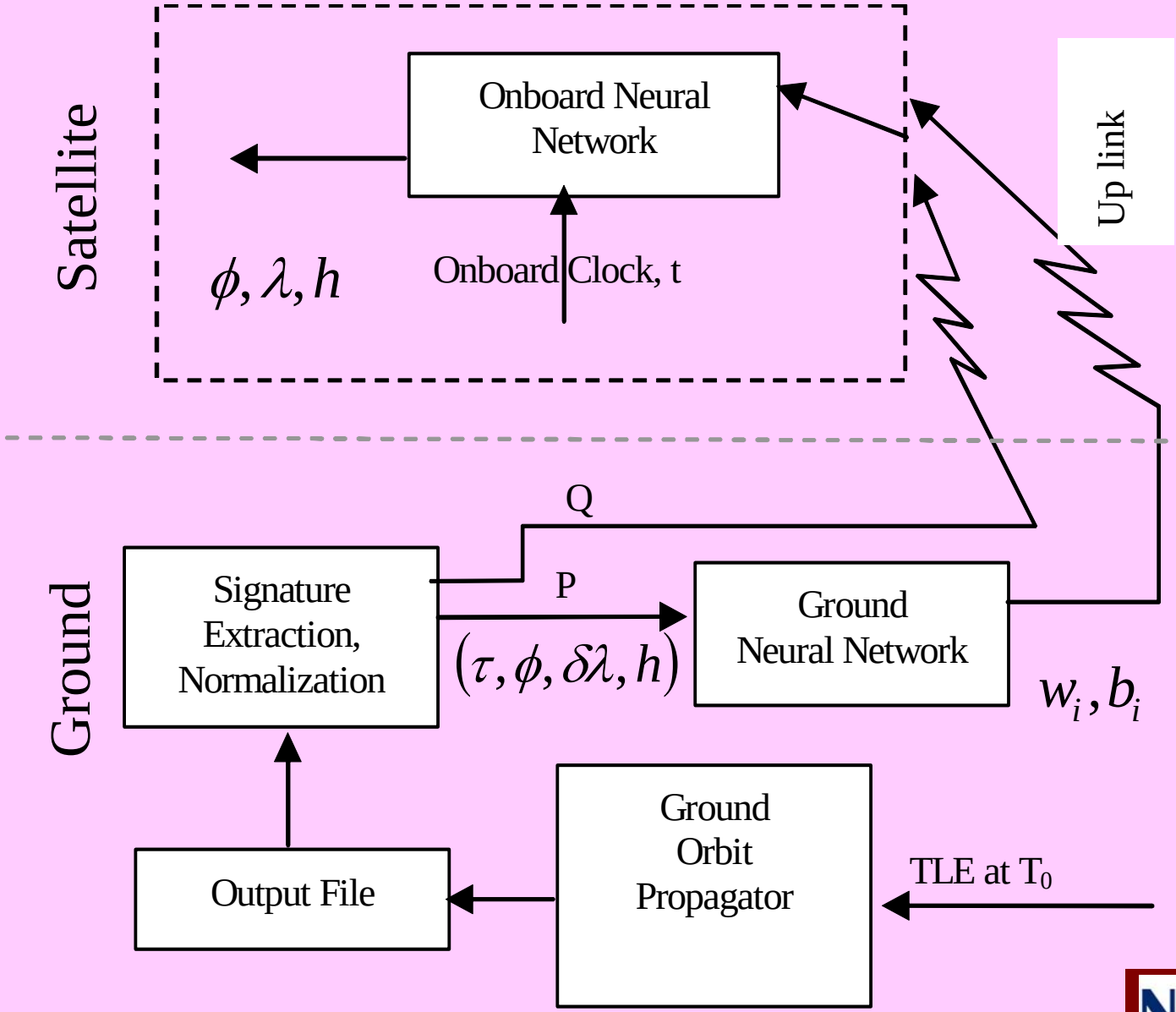


Select GPS or ANN

$\bar{V}_p$



Proposed Scheme



Conclusion

- ANN based orbit prediction can achieve a moderate accuracy of 0.08 deg in ϕ, λ
- No more than 10 neurons required for a neural network for each of ϕ, λ, h.
- Failure detection with a delay of less than 3 samples is feasible.
- Failure detection logic is able to combine the outputs of GPS Rx and ANN using the weighted combination

Thank You for the Attention