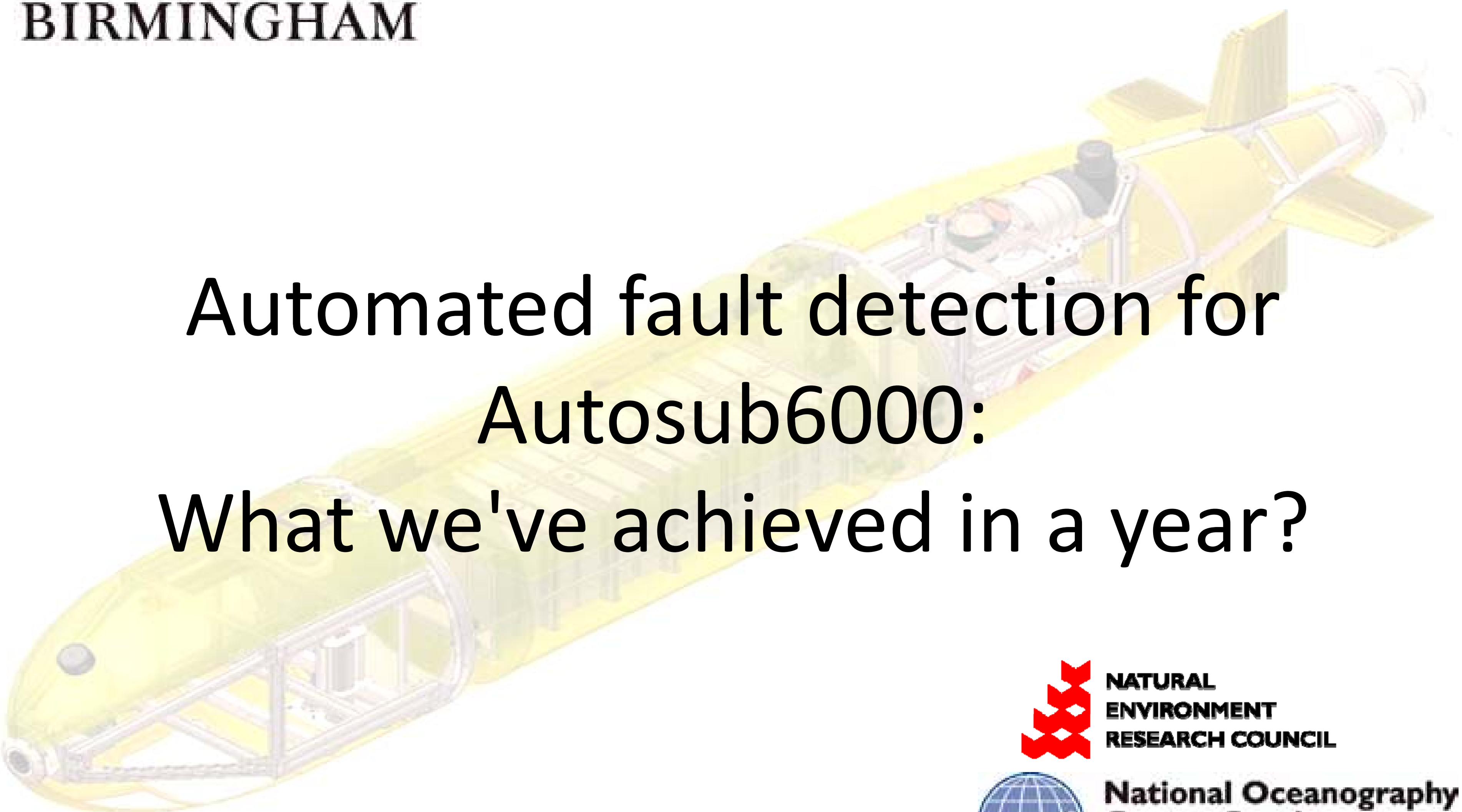
UNIVERSITY OF BIRMINGHAM



Automated fault detection for Autosub6000: What we've achieved in a year?

NATURAL ENVIRONMENT RESEARCH COUNCIL

National Oceanography Centre, Southampton
UNIVERSITY OF SOUTHAMPTON AND NATURAL ENVIRONMENT RESEARCH COUNCIL

TSEM talk @ Institute of Cybernetics, Tallinn, Estonia

Juhan Ernits, March 9, 2010

UNIVERSITY OF BIRMINGHAM

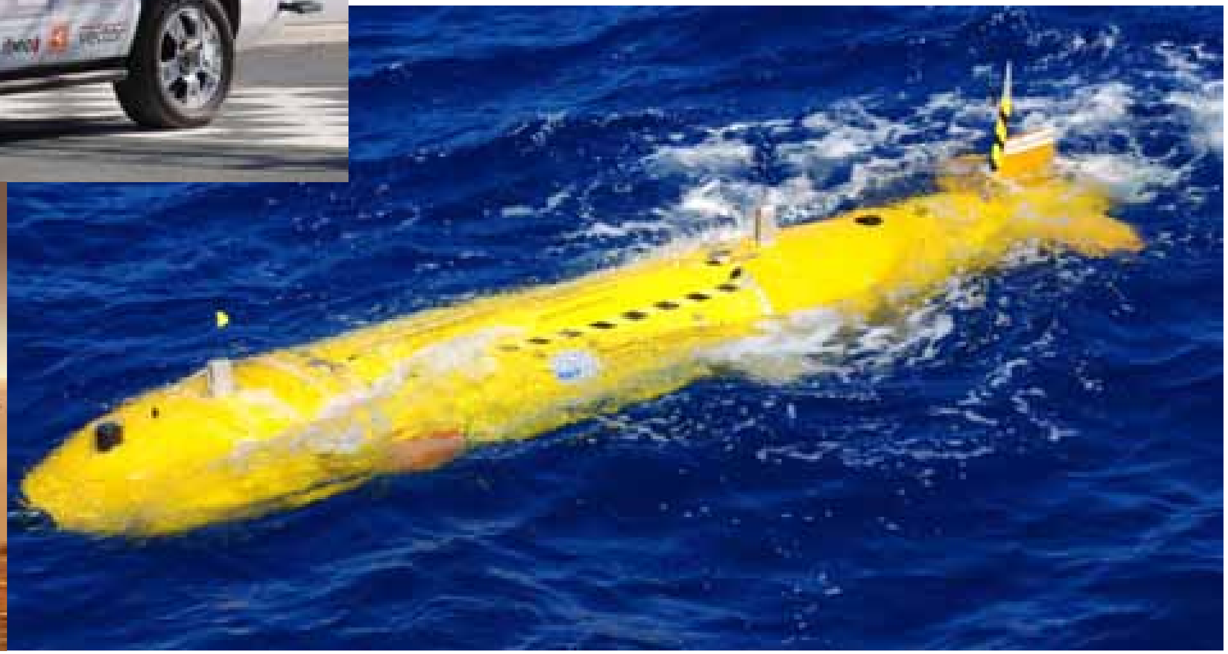
Overview of today's talk

- Automated fault diagnosis for Autosub 6000 AUV – motivation and goals
- Overview of different diagnosis methods
- A closer look at model-based (consistency based) diagnosis
- Diagnosis and mission scripts

UNIVERSITY OF BIRMINGHAM

Diagnosis problem

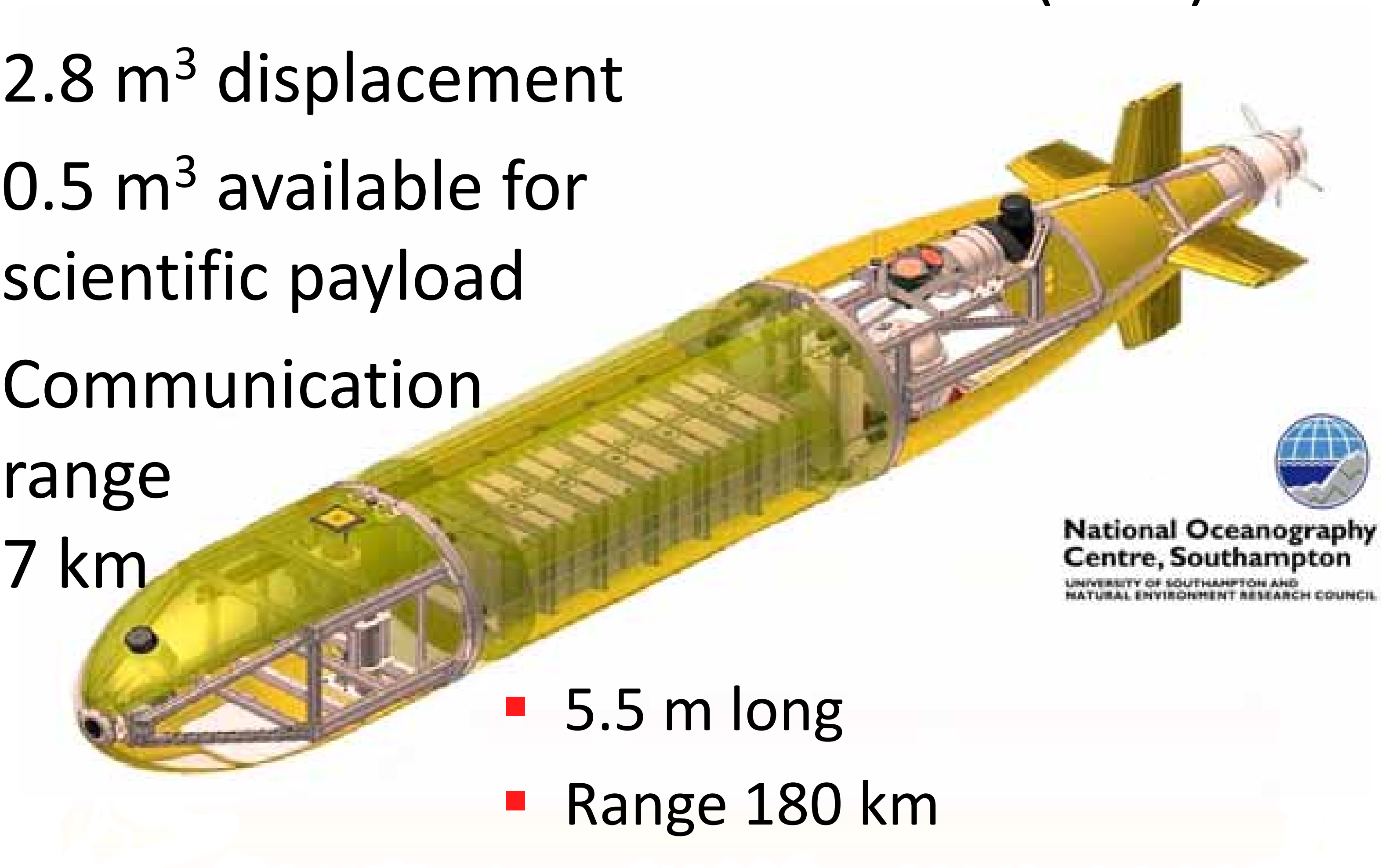
The diagnosis problem is to determine the state of a system over time given a stream of observations of that system.



UNIVERSITY OF BIRMINGHAM

Autosub 6000 AUV

- Autonomous Underwater Vehicle (AUV)
- 2.8 m^3 displacement
- 0.5 m^3 available for scientific payload
- Communication range 7 km



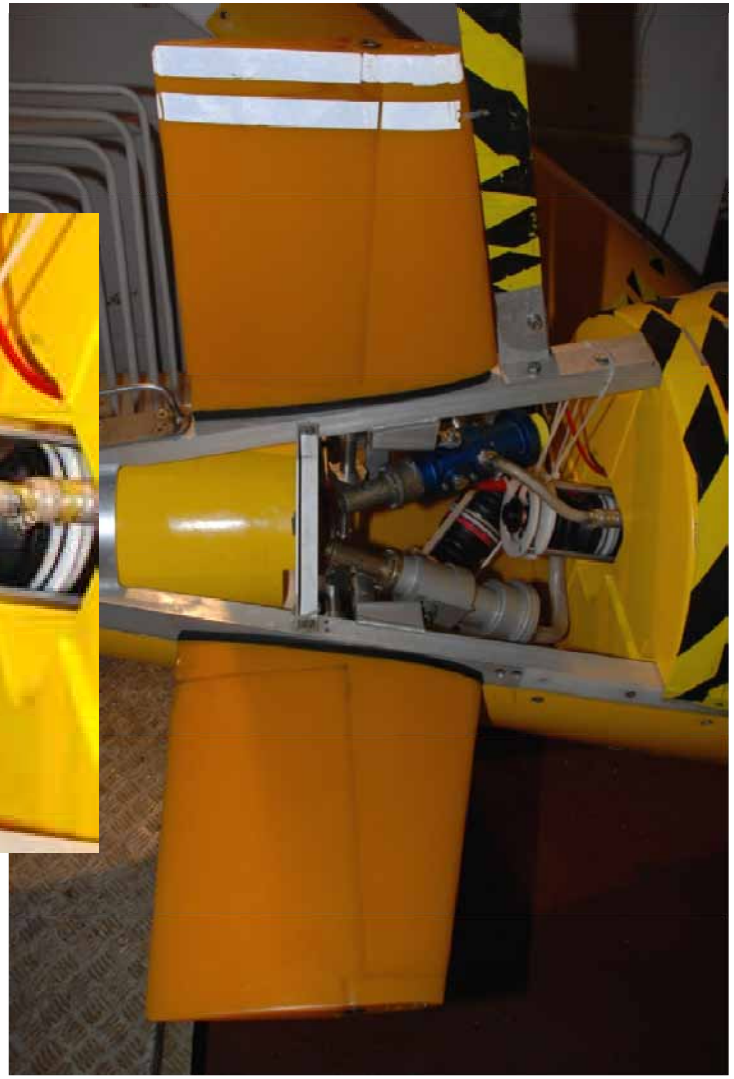
- 5.5 m long
- Range 180 km
- Mission duration up to 60 h

UNIVERSITY OF BIRMINGHAM Autosub 6000 and Faults

- Autosub 6000 and its predecessors have completed > 400 missions
- There have been
  - Near losses, vehicle had to be rescued by a ROV
  - Actual loss, 17 km under 200 m thick Fimbul Ice Shelf in the Antarctic
- There is logged mission data with samples of nominal behaviour and a number of faults that have occurred
  - Knocked stern plane
  - Failure of connectors
  - Failure of servo potentiometre
- Collision with seabed is one of the primary causes of potential vehicle loss

UNIVERSITY OF BIRMINGHAM

Actuators: Motor, Rudder, Stern Plane and Abort Weights



Rudder

Stern plane

Abort weight

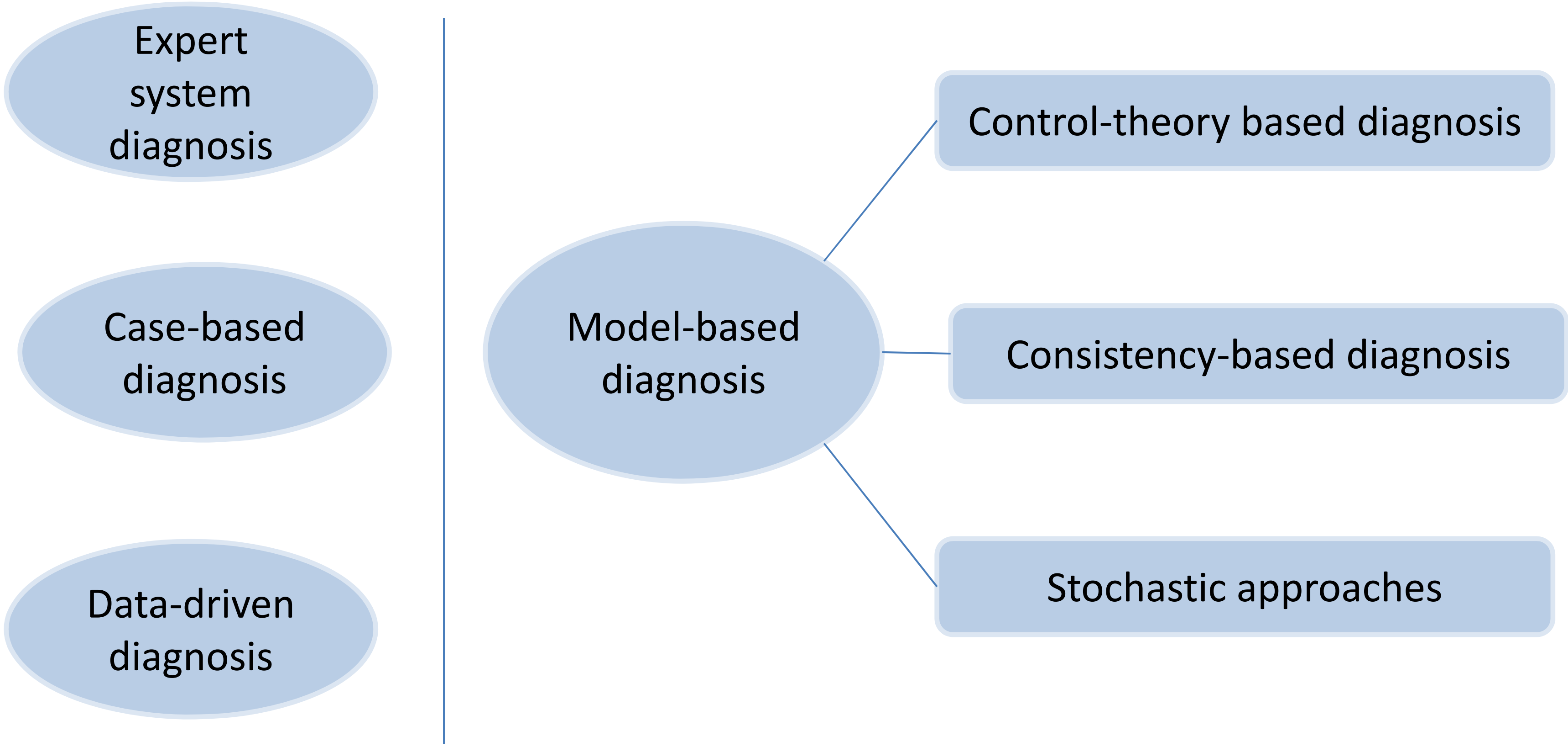
UNIVERSITY OF BIRMINGHAM

Sensed data

- Depth (pressure)
- Altitude (ADCP)
- Ground speed / water speed (ADCP)
- Power consumption, ground faults, battery faults (various sensors)
- Attitude, pitch, roll (INS)
- GPS (only on surface)
- Temperatures, leaks,
- Propeller RPM, stern plane angle, rudder angle
- ...

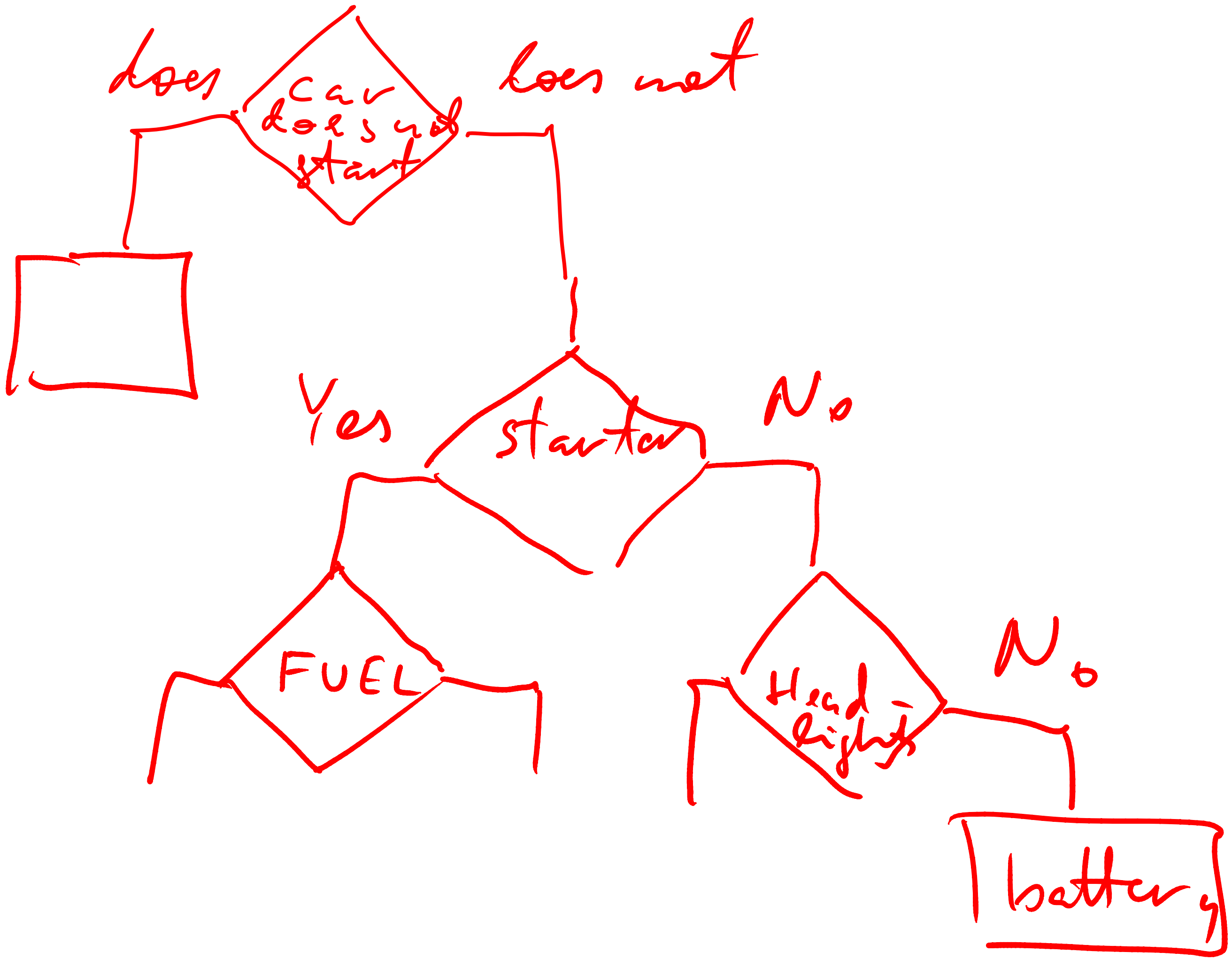
UNIVERSITY OF BIRMINGHAM

Automated Diagnosis



UNIVERSITY OF BIRMINGHAM

Fault trees



UNIVERSITY OF BIRMINGHAM

Problems with fault trees

- Trees can get very large
- Trees are hard to maintain
- Trees cannot be (easily) used for continuous diagnosis

UNIVERSITY OF BIRMINGHAM

Case based diagnosis

- A database of previous experience
  - Look for previous cases with similar symptoms in the database
  - If there are any, see what was done and what was the outcome
- Can be very useful for e.g. copiers (Xerox)
- Again, cannot be used continuously.
- Requires feedback to be generated for each case.

UNIVERSITY OF BIRMINGHAM

Data-driven diagnosis

- E.g. Principal Component Analysis (PCA), Fisher discriminant analysis; Partial least squares; Canonical variate analysis
- The idea (PCA):
  - Capture data from a nominally behaving system.
  - Use eigenvector decomposition of the correlation matrix of the process variables.
  - Eigenvectors provide a sensitive means for discovering variances in correlations between different variables.

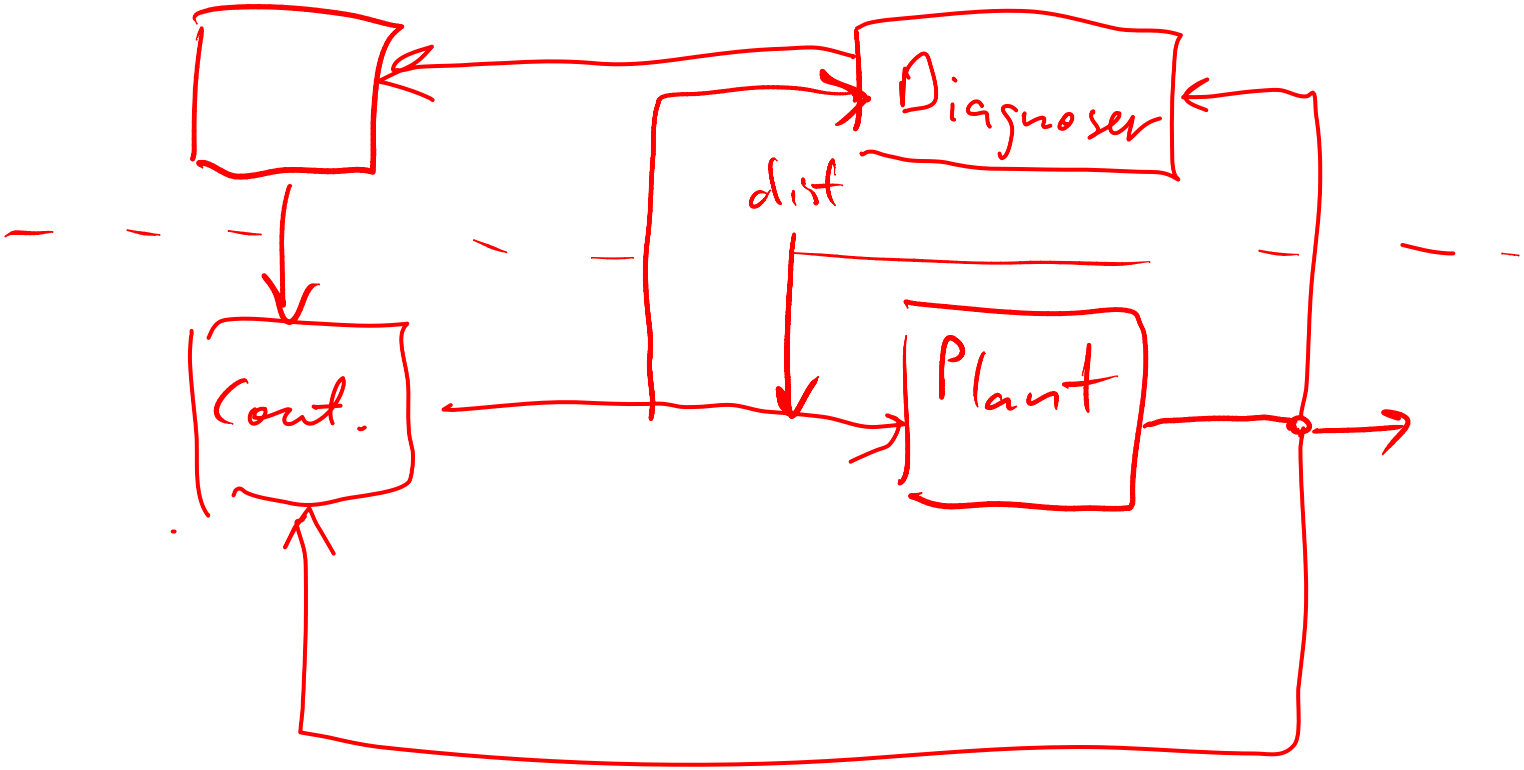
UNIVERSITY OF BIRMINGHAM

Data-driven diagnosis

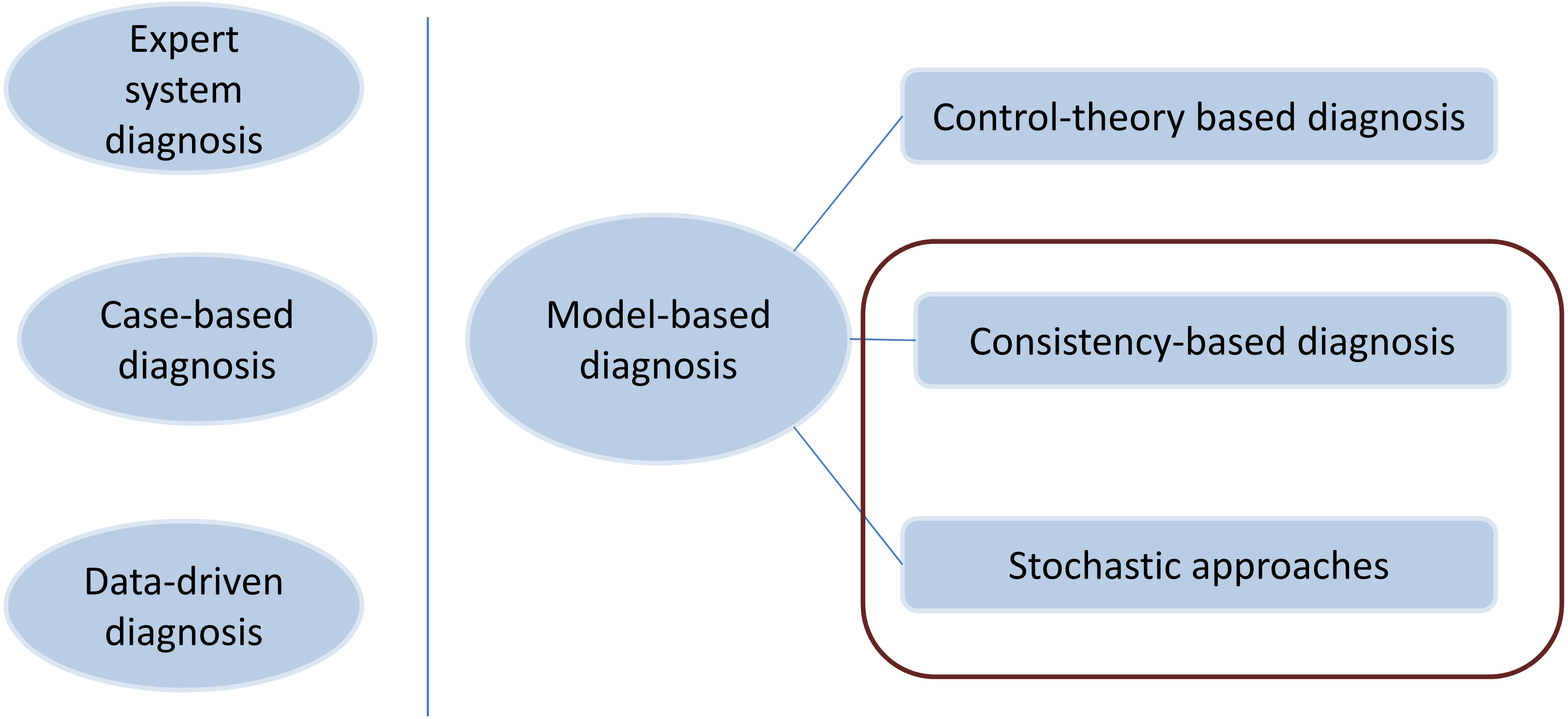
- Can be used for continuous processes
- Are used widely in e.g. chemical plants
- Do not play that well with discrete changes of modes which change the correlation between variables.

UNIVERSITY OF BIRMINGHAM

Control theory based diagnosis



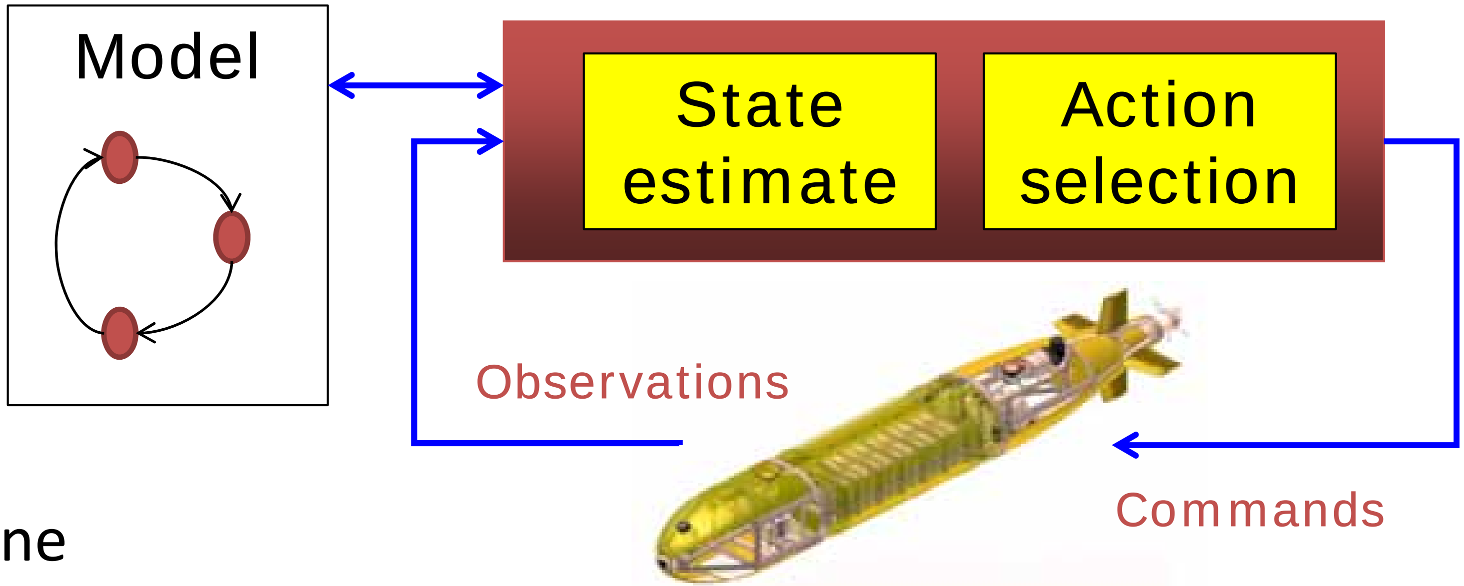
Automated Diagnosis



UNIVERSITY OF BIRMINGHAM

Fault Diagnosis and Recovery

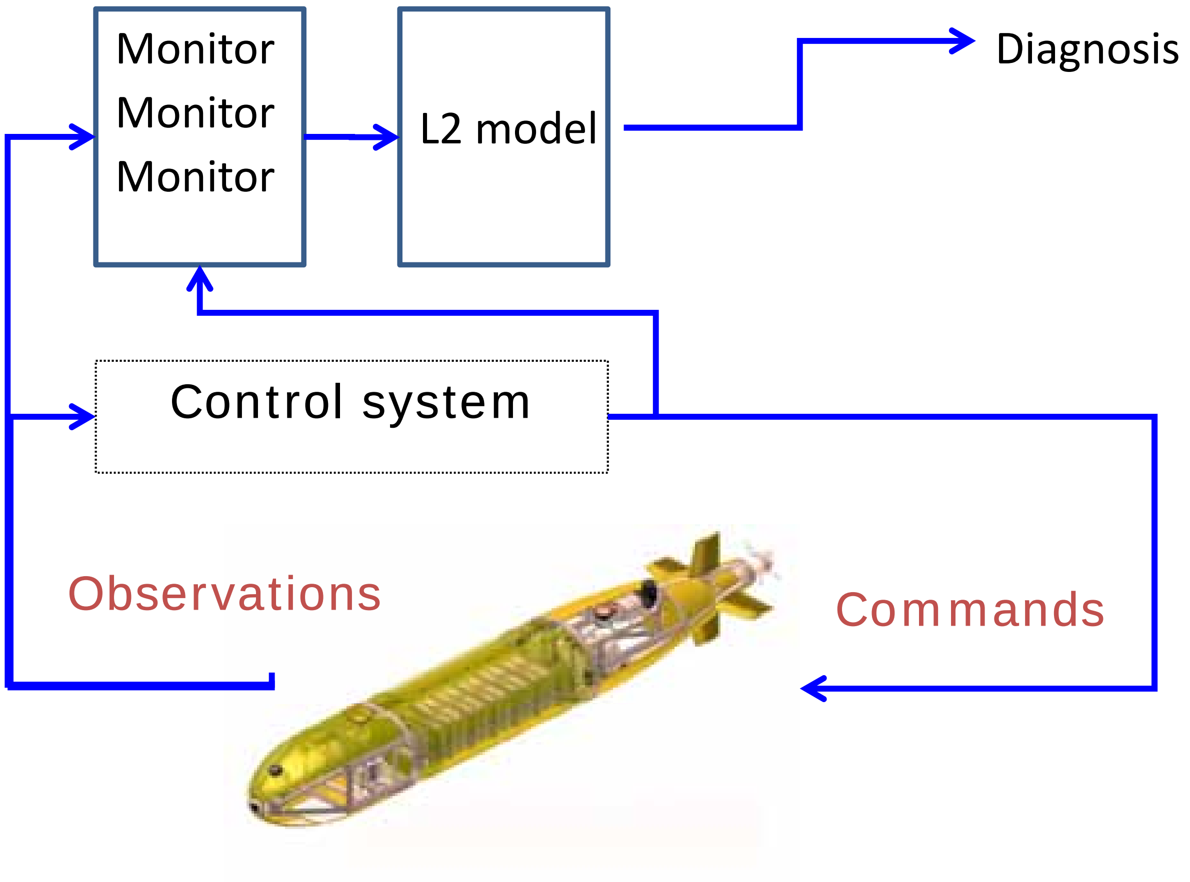
- We use Livingstone 2 model-based diagnosis engine
- Given:
  - A model of a physical system (similar to model programs)
  - The actions taken and observations received thus far



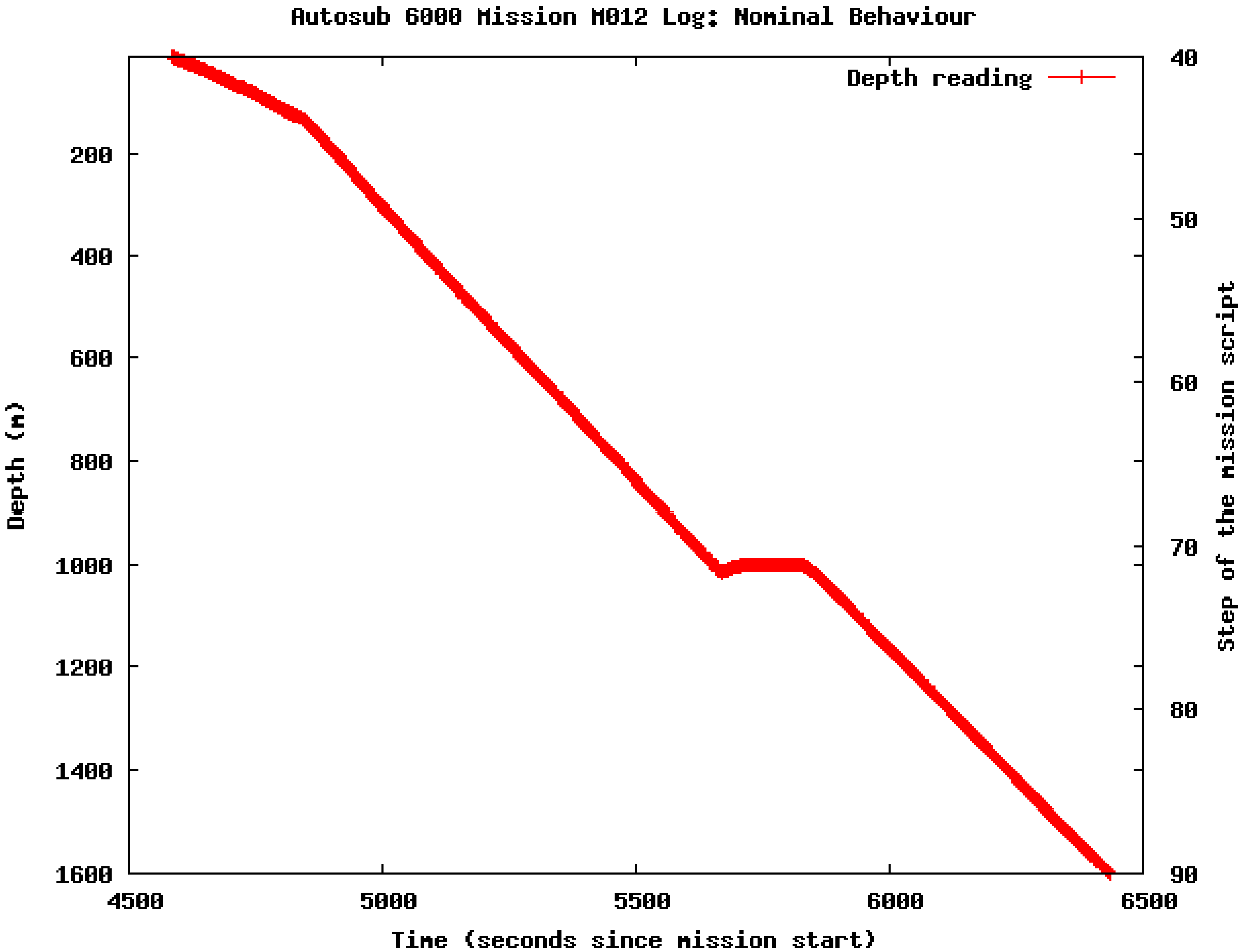
- Determine
  - Most likely states of the system – mode identification
  - Commands needed to move to a desirable state – recovery

UNIVERSITY OF BIRMINGHAM

Livingstone 2 for A6K

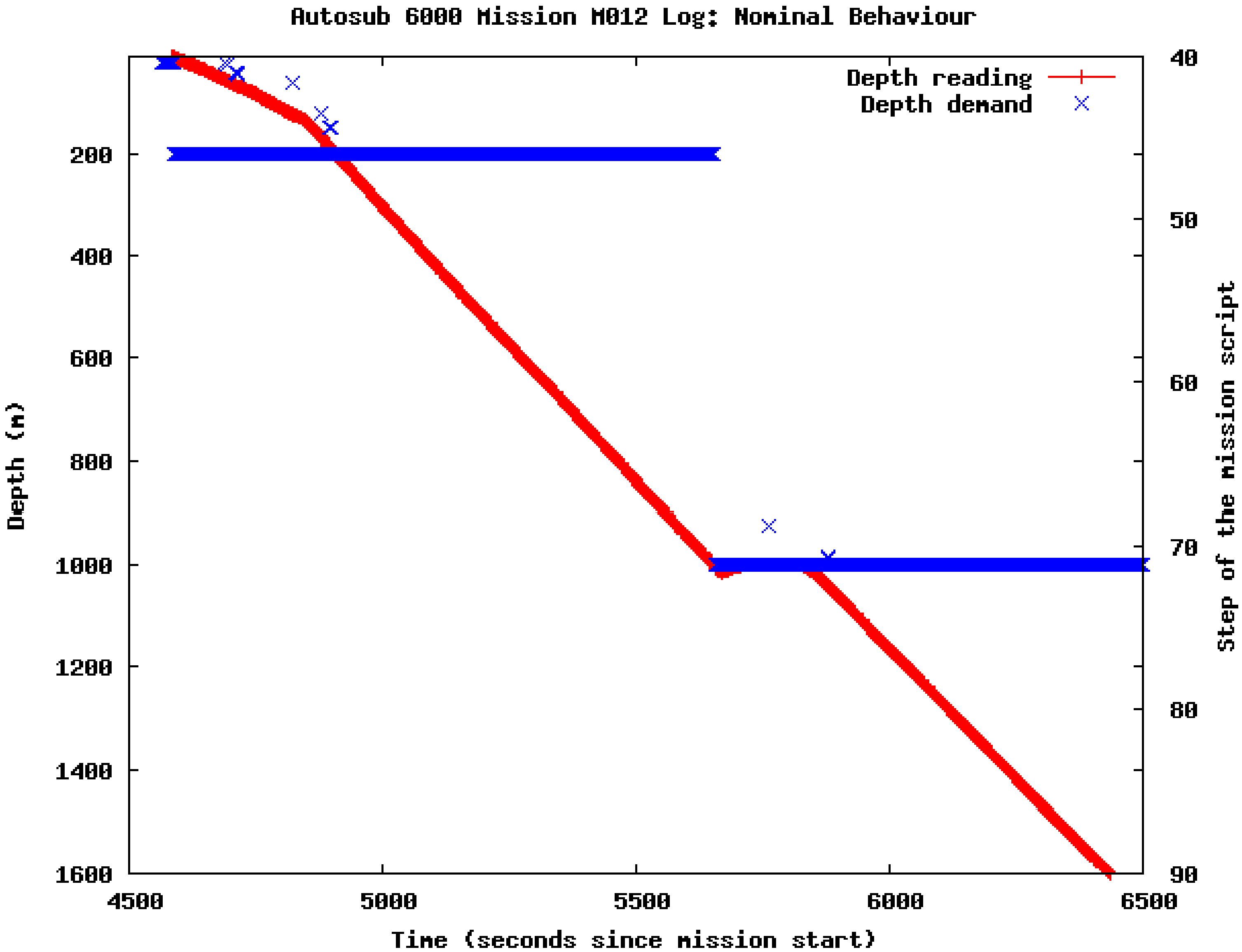


Example: Nominal Behaviour



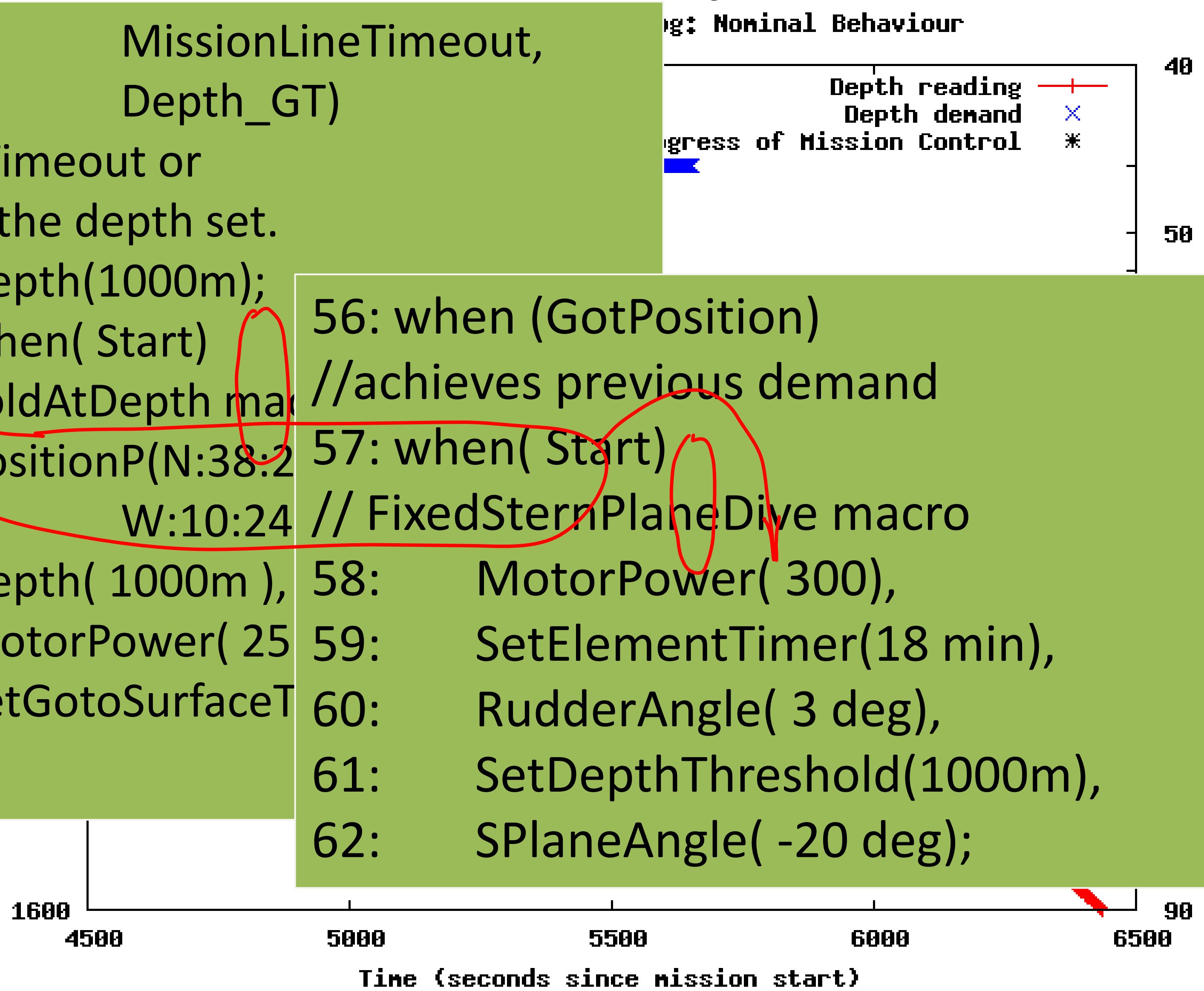
UNIVERSITY OF BIRMINGHAM

Example: Depth Demand



Example: Role of the Mission Script

UNIVERSITY OF BIRMINGHAM




```
63: when(        MissionLineTimeout,
                 Depth_GT)
// When Timeout or
// passed the depth set.
64:      Depth(1000m);
65:      when( Start)
// start HoldAtDepth ma
66:      PositionP(N:38:2
                 W:10:24
67:      Depth( 1000m ),
68:      MotorPower( 25
69:      SetGotoSurfaceT
```

```
56: when (GotPosition)
//achieves previous demand
57: when( Start)
// FixedSternPlaneDive macro
58:      MotorPower( 300),
59:      SetElementTimer(18 min),
60:      RudderAngle( 3 deg),
61:      SetDepthThreshold(1000m),
62:      SPlaneAngle( -20 deg);
```

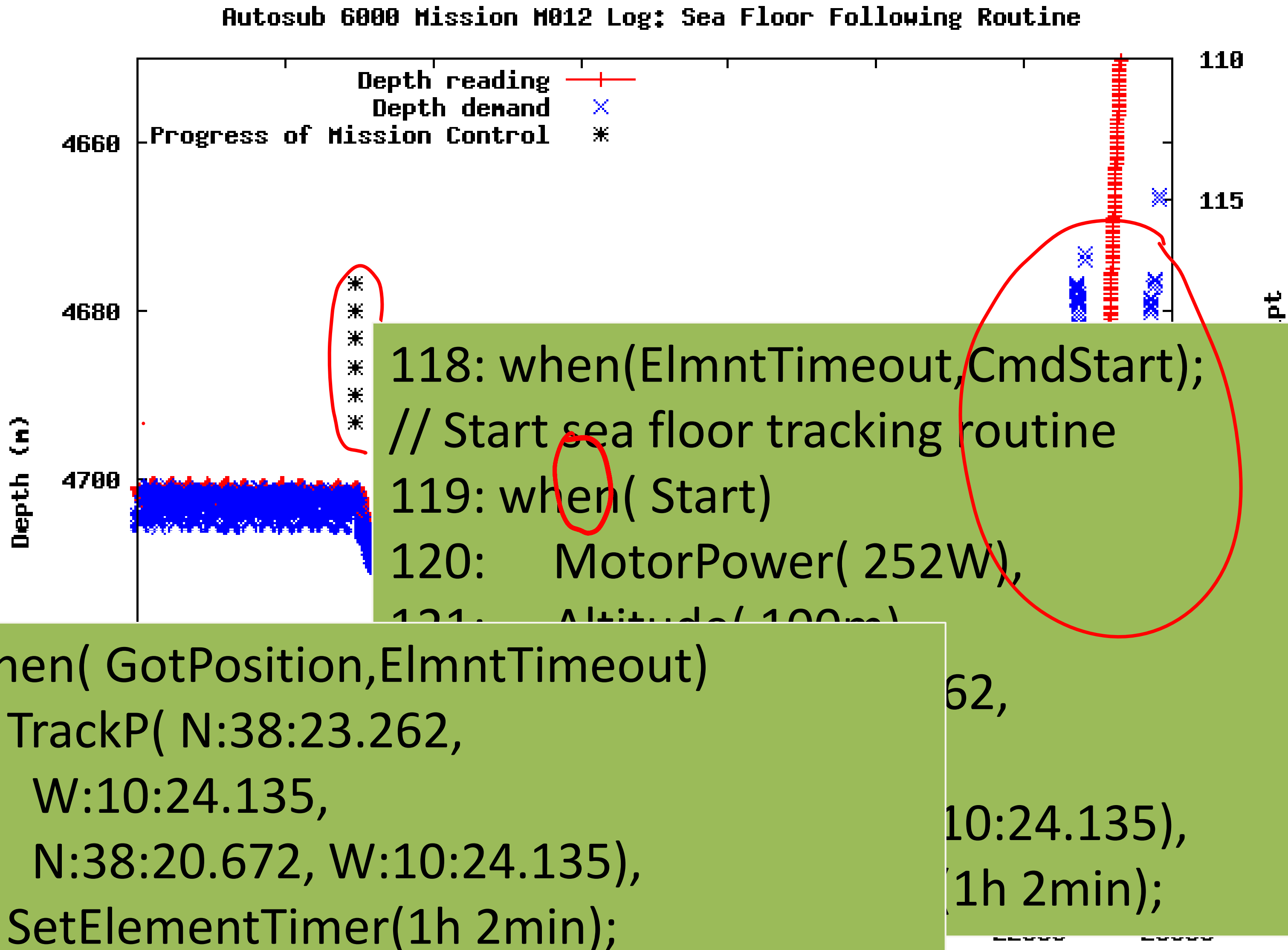
UNIVERSITY OF BIRMINGHAM

Configuration

- A number of parameters are set in the configuration scripts
- Domain axioms are based on domain knowledge from the engineers
- Example:

Variable Type	Variable name	Invariant condition
UNVT_MaxMinLim	ncSplaneLimits	Stern plane max min limits compared to physical capability of the control surface
UNVT_float_type	ncMaxDepth	ncSafeMaxDepth $<$ Abort Weight Release max depth
UNVT_float_type	ncMinDepth	ncMinDepth $<$ Max depth
UNVT_float_type	ncSafeMaxDepth	ncSafeMaxDepth $<$ Abort Weight Release max depth
UNVT_float_type	ncSafeMinDepth	ncSafeMinDepth $<$ Max depth
UNVT_float_type	ncFwdScaleUp	ncFwdScaleUp $\in [0, 1]$
UNVT_float_type	ncFwdScaleDn	ncFwdScaleDn $\in [0, 1]$
Boolean	nci_sim_mode	Must be false

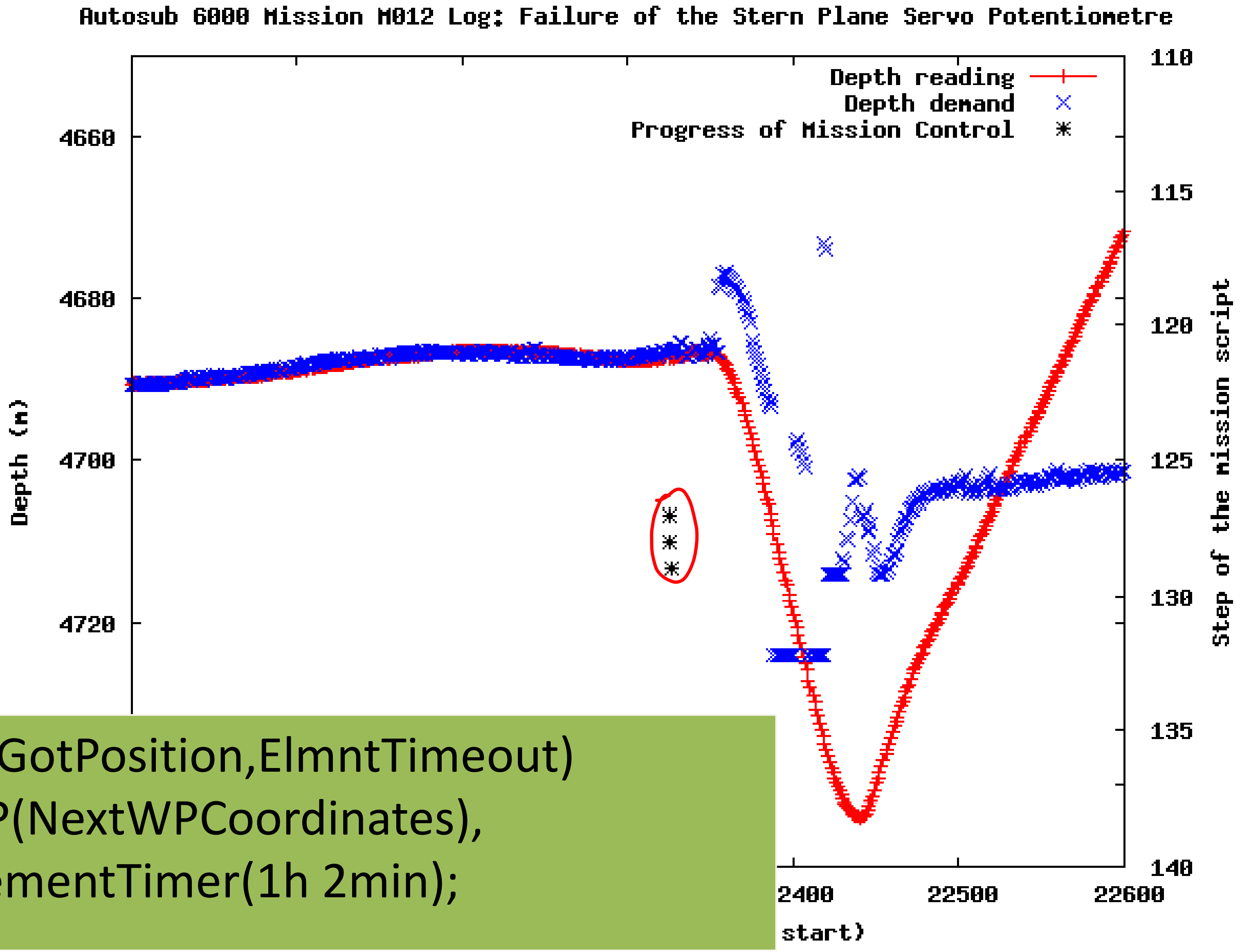
Depth Demand Revisited



118: when(ElmntTimeout,CmdStart);
// Start sea floor tracking routine
119: when(Start)
120: MotorPower(252W),

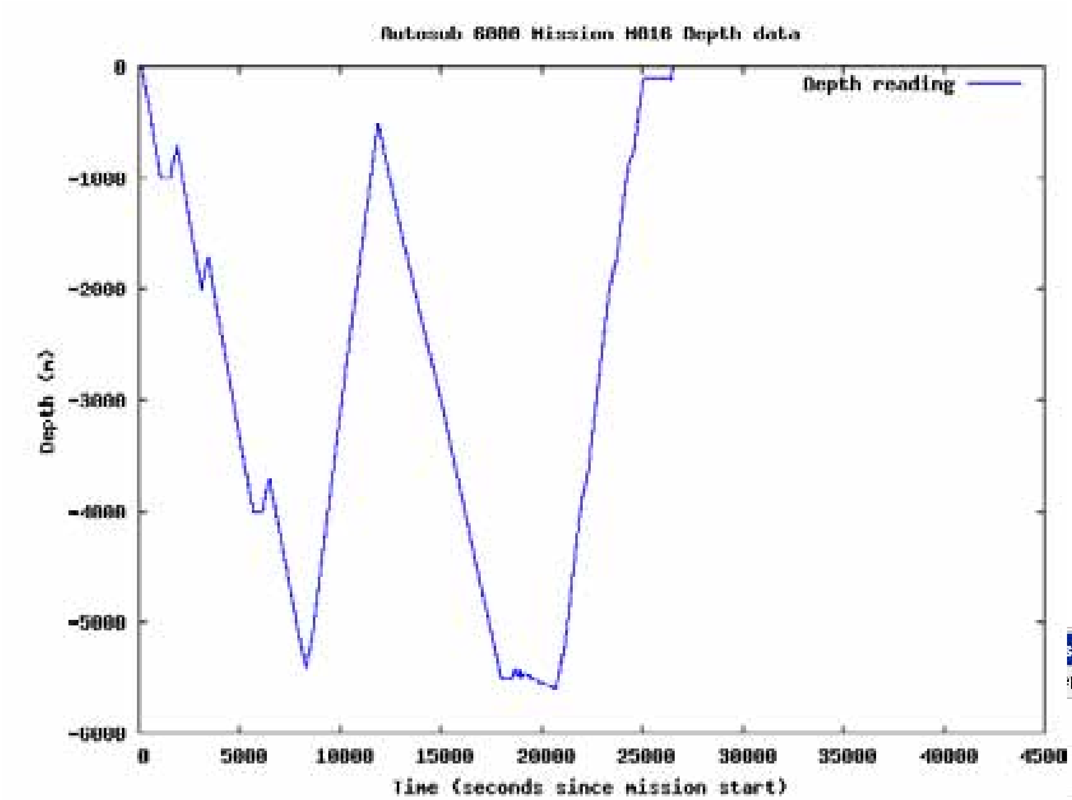
124: when(GotPosition,ElmntTimeout)
125: TrackP(N:38:23.262,
W:10:24.135,
N:38:20.672, W:10:24.135),
126: SetElementTimer(1h 2min);

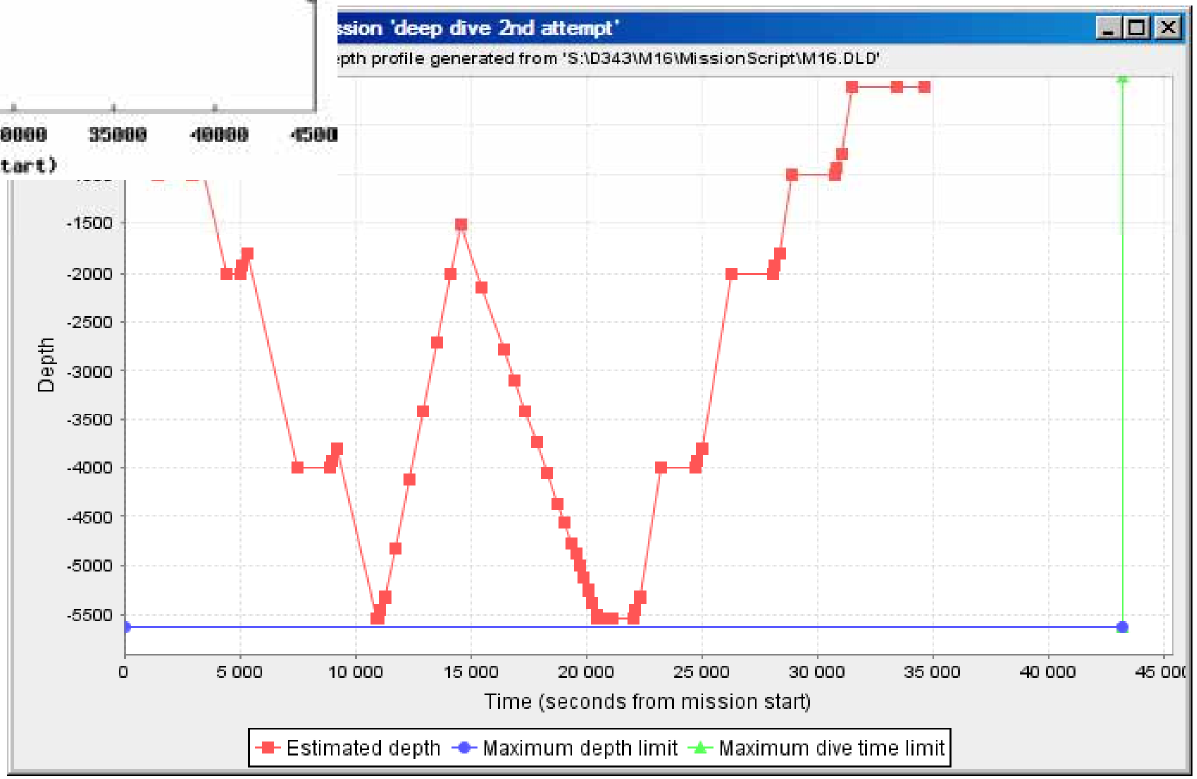
Mission Script and Fault Context




```
when( GotPosition,ElmntTimeout)
 TrackP(NextWPCoordinates),
 SetElementTimer(1h 2min);
```

Depth profile





UNIVERSITY OF BIRMINGHAM

Stochastic approaches: Particle Filters

1. For N particles $p^{(i)}, i = 1, \ldots, N$, sample discrete modes $z_0^{(i)}$, from the prior $P(Z_0)$.
2. For each particle $p^{(i)}$, set $\mu_0^{(i)}$ and $\Sigma_0^{(i)}$ to the prior mean and covariance in state $z_0^{(i)}$.
3. For each time-step t do

(a) For each $p^{(i)} = (z_{t-1}^{(i)}, \mu_{t-1}^{(i)}, \Sigma_{t-1}^{(i)})$ do

i. Sample a new mode:

$$\hat{z}_t^{(i)} \sim P(Z_t | z_{t-1}^{(i)})$$

ii. Perform Kalman update using parameters from mode $\hat{z}_t^{(i)}$:

$$(\hat{y}_{t|t-1}^{(i)}, \hat{S}_t^{(i)}, \hat{\mu}_t^{(i)}, \hat{\Sigma}_t^{(i)}) \leftarrow KF(\mu_{t-1}^{(i)}, \Sigma_{t-1}^{(i)}, y_t, \theta(z_t^{(i)}))$$

iii. Compute the weight of particle $\hat{p}^{(i)}$:

$$w_t^{(i)} \leftarrow P(y_t | \hat{y}_{t|t-1}^{(i)}, \hat{S}^{(i)}) = N(y_t; \hat{y}_{t|t-1}^{(i)}, \hat{S}^{(i)}).$$

(b) Resample as in step 3.(b) of the PF algorithm (see Figure 1).

UNIVERSITY OF BIRMINGHAM

Conclusion

- Autosub 6000 AUV is a great platform automated diagnosis.
- We generate diagnosis components corresponding to mission scripts to infer the internal state of the system
  - During diagnosis component generation we analyse mission scripts and configuration for inconsistencies
  - We provide an estimated depth profile for pre-mission validation.
- Current work: we generate components from the mission script for diagnosis model that work on-board on the vehicle and off-board using telemetry data
- We are looking into ways to write hybrid diagnosis models in a systematic way