APPLIED STATE ESTIMATION

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INTRODUCTION.

State estimation of dynamic systems plays a key role in monitoring and controlling such systems. State estimates are used for health status check in order to maintain safe operations of systems and processes. Also, it is used to optimally control the dynamic system under consideration. Research results obtained in applying state estimation in aerospace, oil and gas, and energy are presented.

RESULTS AND DISCUSSION.

1 - Spacecraft Spin Axis Attitude Determination. Spacecraft spin axis attitude determination and control is essential for fulfilling the mission functions of a spacecraft. The spin axis attitude must fulfil norm constraints. The geometrical illustration of the problem is as depicted in Figure 1 below.

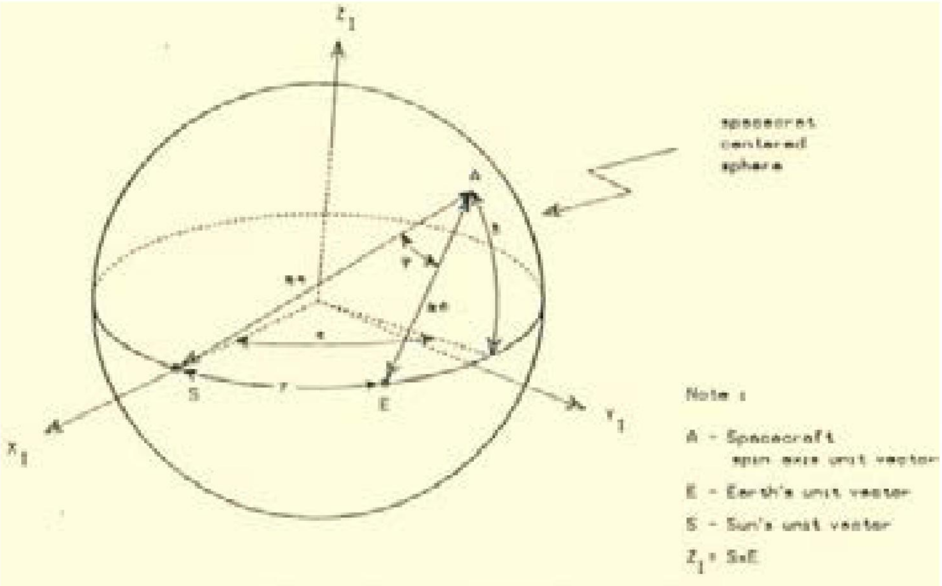


Fig. 1. Attitude determination geometry.

In this research two estimation algorithms are developed to solve this problem. The computational requirements and the resulting attitude determination accuracy of the developed spin axis attitude determination algorithms are shown in Tables 1 and 2.

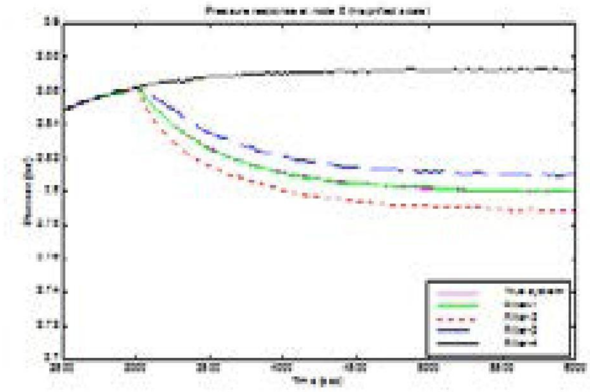
2 - Pipeline Monitoring. Pipeline fluid transport is essential for the success and safety of oil and gas industrial operations. Dynamic monitoring of pipeline operation is a possible mean to insure the safe operation of pipelines transporting fluids. State estimation can provide the basis for real-time monitoring of fluid flow in pipelines. Here dynamic state estimation is applied to detect and locate leaks in pipelines. The developed scheme possesses many desirable features: it can readily detect and isolate leaks in the transient phase as well as in the steady state phase of the pipeline dynamic operation. It lends itself to on-line computer monitoring. It relies on only few measurements. Thus, it lends itself to engineering applications where intermediate measurements may be inaccessible, and not withstanding the expense of installing additional transducers. The following figures give the results in terms of estimated pressures and flow rates upstream and downstream of a leak occurring at time of 3000 s.

Table 1. Estimation error statistics of the two algorithms

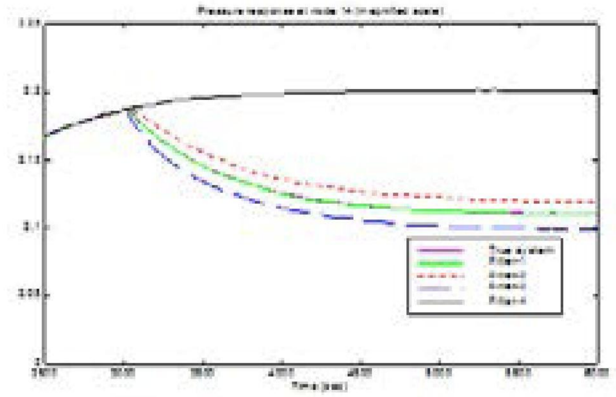
Number of readings		4	6	8	10
Algorithm 1	Mean	0.0119	0.0105	0.0086	0.0075
	SD	0.0061	0.0051	0.0056	0.0043
Algorithm 2	Mean	0.2825	0.1442	0.0725	0.0248
	SD	0.1299	0.0301	0.0122	0.0042

Table 2. Computer requirements of the two algorithms considering ten sensor readings.

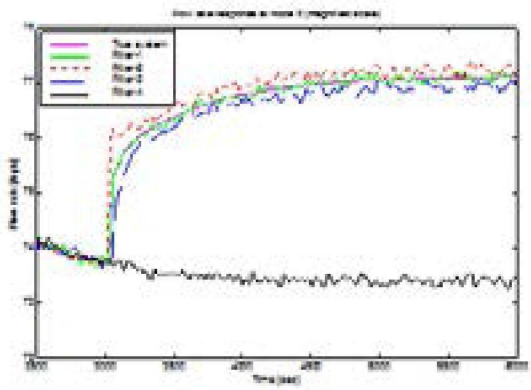
	Run time, seconds		Storage	Major
	Mean	SD	Requirements (Bytes)	Operations count
Algorithm 1	0.1267	0.0017	4708	1204
Algorithm 2	0.082	0.0083	3932	1020



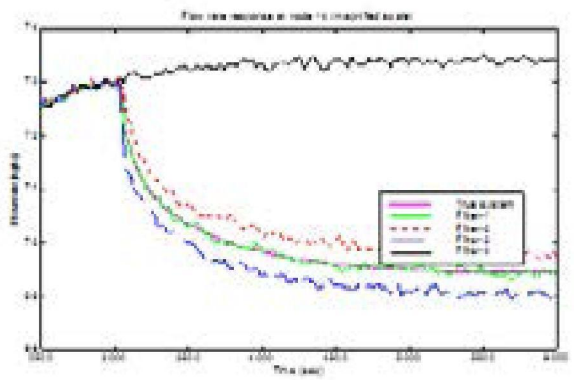
Upstream pressure response after a leak.



Downstream pressure response after a leak.



Upstream flow rate response after a leak.



Downstream flow rate response after a leak.

***Figure 2.** Pressure and flow rate response after a leak.*

Table 3 gives the mean time in minutes for detection and isolation of leaks considering perfect modeling as well as modeling with uncertain parameters. These results show the effectiveness of the scheme in detecting and isolating leaks of different magnitudes.

Table 3. Mean time for detection and isolation of leaks.

Leak size	Accurate Parameter	1% Parameter Mismatch
1%	11.7 min	15.2 min
5%	2.3 min	6.0 min
10%	1.8 min	min

3 - Boiler Operation Scenarios Testing. Boilers are main components of many process industries as well as conventional power generation industries, e.g. oil, gas, coal fired and nuclear. Therefore, their safe operation is of vital importance. Boiler operation scenarios can effectively be tested and verified before actual implementation using dynamic modeling. In this research a boiler dynamic model is developed and used to test and verify various operational scenarios to prevent the possibility of tube overheating. A schematic illustrating the model is shown in Fig. 3.

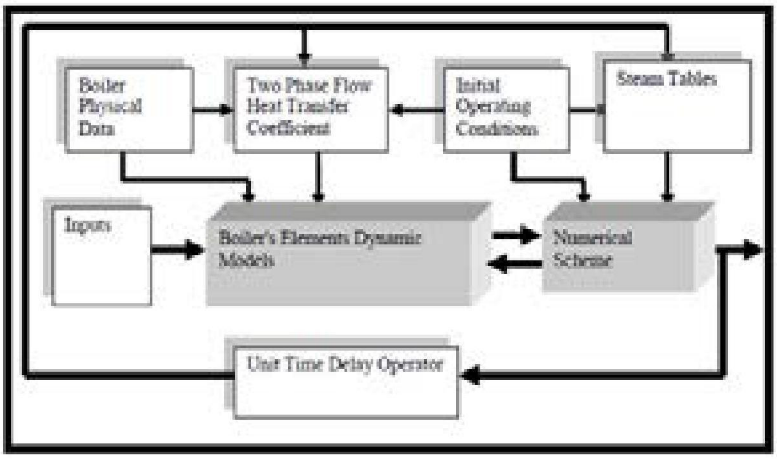


Figure 3. *Schematic illustration of the dynamic model.*

A scenario of steam demand increase followed by feed water supply change is considered. The resulting dynamic response to this scenario in terms of steam temperature T_s, the boiler tubes inner wall temperature T_i, and outer wall temperature T_o are as shown in Fig. 4 below.

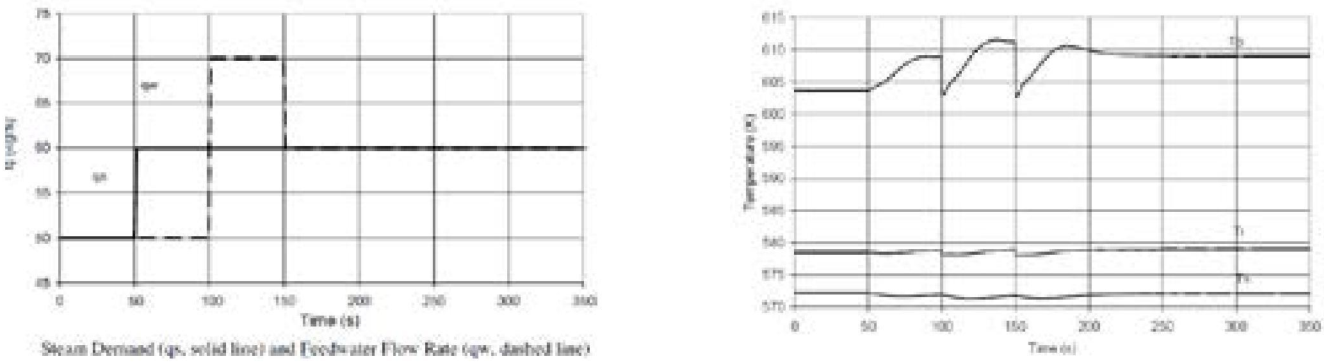


Figure 4. *Operational scenario and the resulting steam and boiler tubes thermal response.*

CONCLUSIONS.

Three case studies; in aerospace, oil and gas, and energy; described above illustrate the use of state estimation for engineering systems operation monitoring, safe operations and control. Applications in other areas of engineering, e.g. renewable energy, environmental studies, bioengineering, mechatronics, transportation engineering, etc. are possible.