Engineering systems, such as transportation vehicles (cars, airplanes, submarines), production facilities (oil refineries, power stations, etc) and others are prone to faults (component malfunctions). These may concern the main equipment or the sensors and actuators interfacing it to a control system. Faults may reduce the efficiency of the system, may jeopardize system mission, they may threaten the health of the system or even human life. A major engineering challenge is the monitoring of our systems, in order to detect the occurrence of faults and to determine their location and size.

Advanced fault detection and isolation (localization) methods utilize a mathematical model of the system and rely on the concept of “analytical redundancy”: actual system outputs are compared to ones predicted by the model and discrepancies are taken as indications of faults. Apart from faults, such discrepancies may also be caused by “nuisances”, such as noise and disturbances, and inaccuracies of the model. Systems diagnostics aims at detecting and isolating faults, with robustness against nuisances.

The analysis relies on “residuals”, representing the difference between outputs and predictions. “Residual generator” algorithms compute these residuals from system input and output measurements, and manipulate them to provide for detection robustness and isolation selectivity. Residual generators are based on various design techniques, including direct manipulation of transfer functions, geometric projection, observers and principal component analysis. These methods will be discussed in the course and it will also be shown, theoretically and by examples, that under certain conditions they all lead to the same residuals. Because of the presence of noise, residuals are subjected to statistical testing; this will also be discussed.

The prior knowledge needed for the course is the representation of discrete linear systems by transfer functions and in the state space. Matrix manipulations and some vector properties will also be utilized. In addition, some very fundamental statistical concepts will be used.

**The lecturer**

Janos Gertler is a Fellow of IEEE and of IFAC and a Foreign Member of the Hungarian Academy of Sciences. He has written a book and more than 80 papers on diagnostics, has given invited plenary lectures on the subject at international conferences in the US, UK, Germany, France, Finland, Hungary and Turkey, and taught several short courses in Spain, Israel and Hungary. He also led a successful application project with General Motors, developing system-level techniques for on-board component fault detection and diagnosis in automotive engines, subsequently implemented on several mass-produced GM car models.
Course outline


Lecture 3. Residual generation by dynamic consistency relations. Inversion approach.

Lecture 4. Systematic design with dynamic consistency relations.


Lecture 7. Residual generation by diagnostic observers.

Lecture 8. Robustness with respect to disturbances and model errors.


Lecture 10. Principal component analysis.

Lecture 11. Detection and isolation with principal component analysis.


Two additional class periods. Discussion of student projects.

Handouts

Powerpoint “slides” will be distributed prior to each lecture.

Projects

There will be three design and simulation projects. These will involve a “personal plant” for everybody, on which various diagnostic techniques will be designed, implemented and tested.

Course grade

30% for each project, 10% for course participation.