Monitoring and Diagnostic Methods for Robots Used in Remediation of Waste Sites

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Goals

- Develop M&D methods that will prevent unexpected robot failures by providing early warning of impending failures
- Focus on hydraulically-powered robots

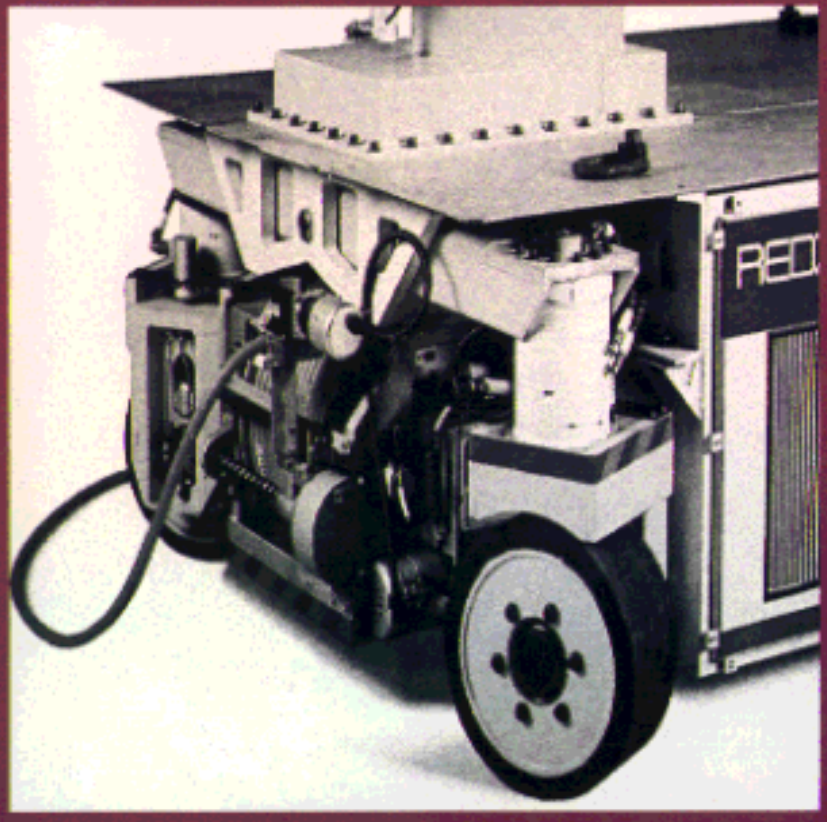
Focus Of Study

- Assess the types of components used on the Rosie Mobile Workstation, developed for DOE by Redzone Robotics. Rosie consists of:
  - Mobile platform (central spine, front & rear drive wheel assemblies, electronics enclosure, hydraulic power supply system, hydraulic filters and valves, tether system)
  - Heavy manipulator (waist rotation, shoulder pitch, forearm extension, wrist pitch)

Rosie Mobile Workstation

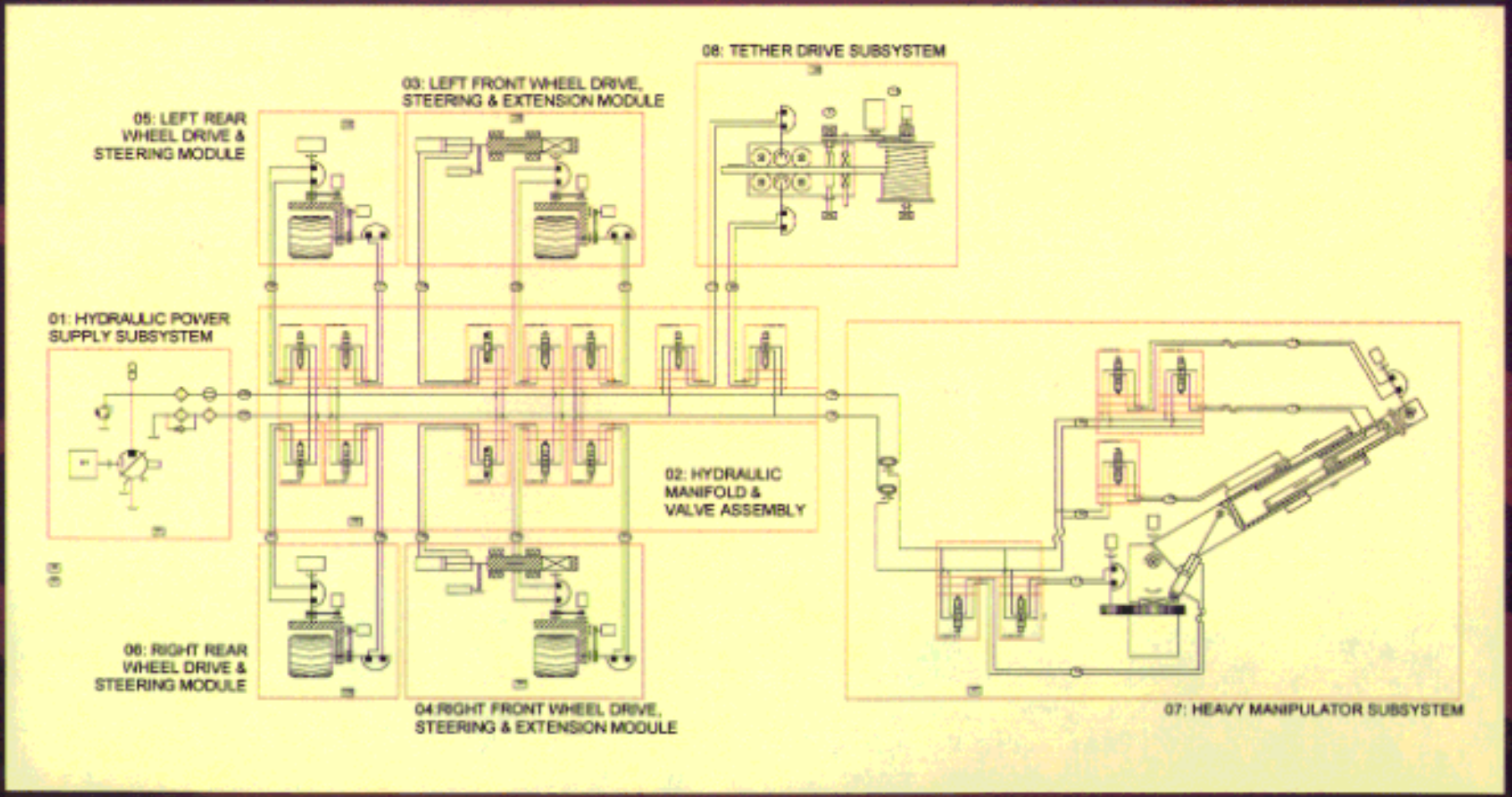
Subsystems to be Studied

- Based on FMEA results, select:
  - Hydraulic Power Supply Subsystem (HPSS)
  - Wheel drive, steering, and extension subsystem



Rosie Wheel and Drive Arrangement

Rosie Hydraulic Subsystem Functions

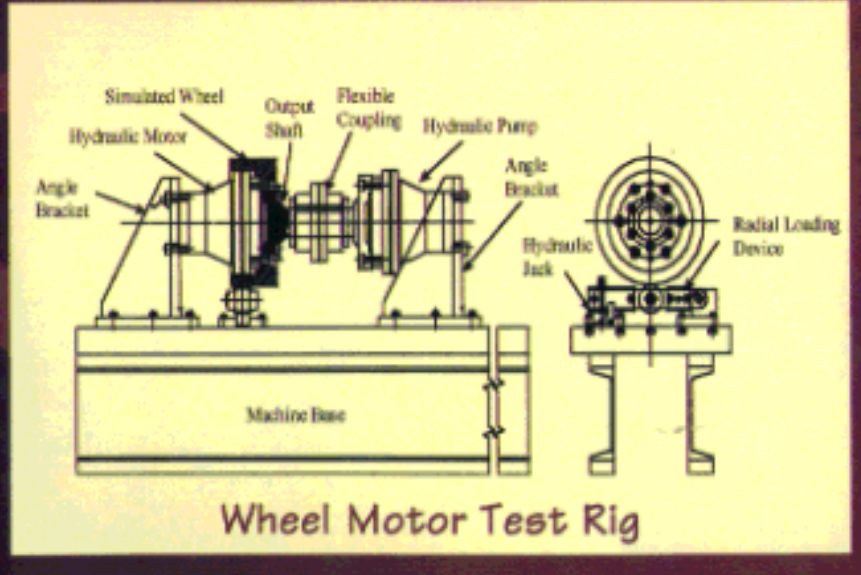


Research Approach

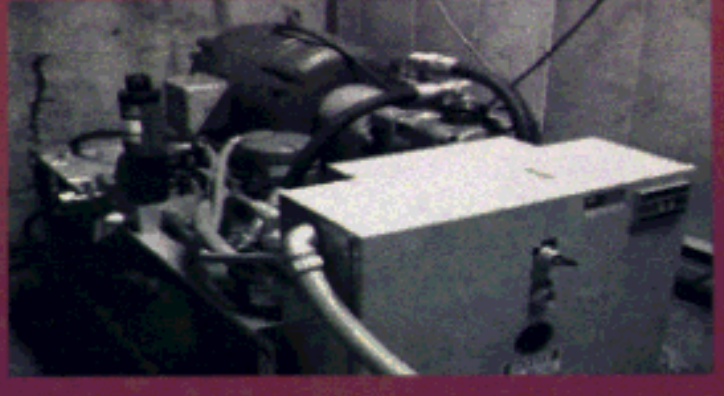
- Create a laboratory simulator for key components
  - Insert a series of controlled faults
  - Record and analyze resulting behavior
  - Develop fault diagnostic technology based on a combination of:
    - Basic diagnostic knowledge and practice
    - Analytical modeling of the system
    - Diagnostic insight based on analysis of the data

Test Rig Components

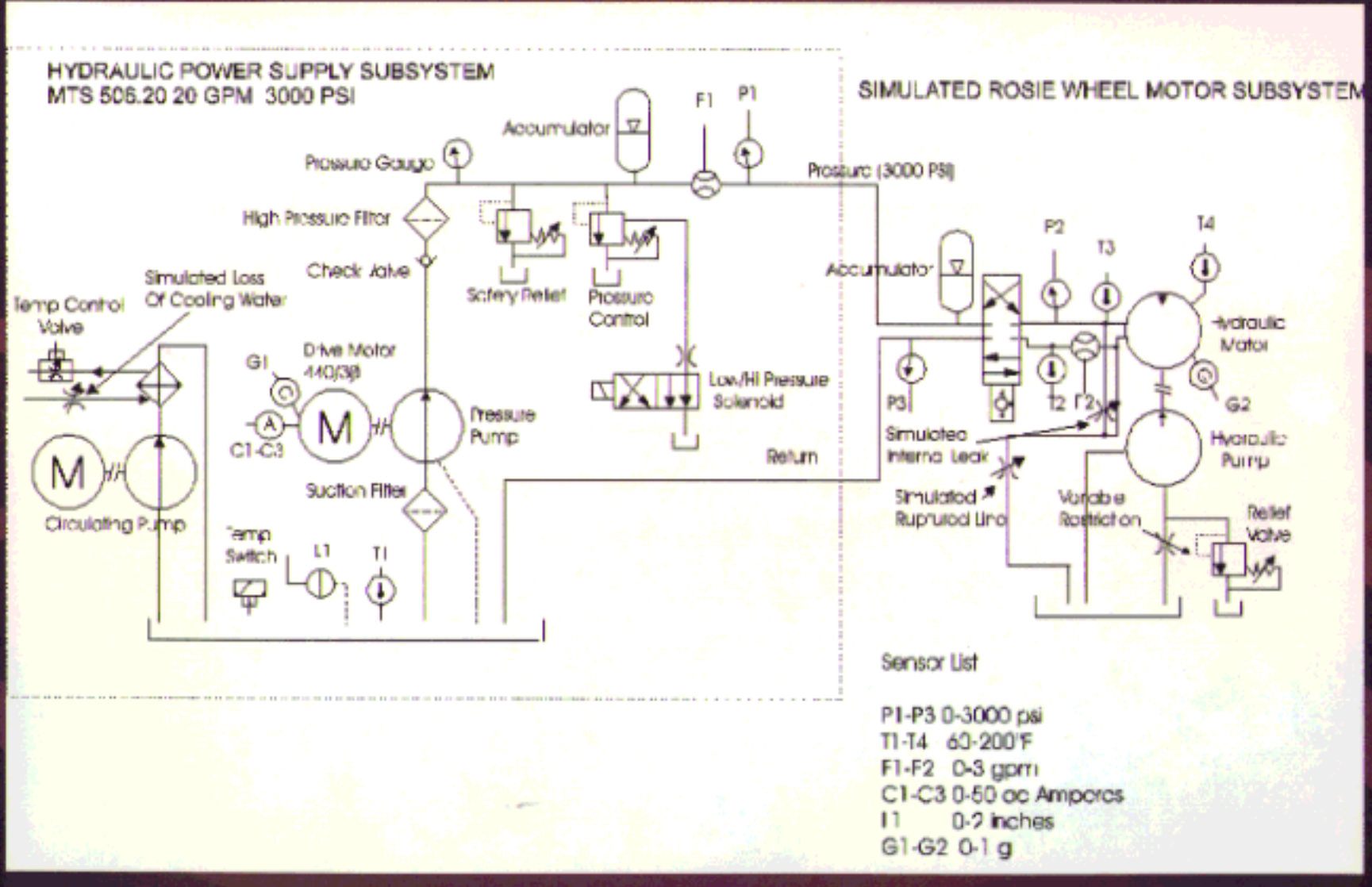
- Hydraulic power supply: existing at FMT; similar in size and power to Rosie
- Rotary actuator (hydraulic motor)
  - Same part number as used on Rosie
  - Use two motors in a back-to-back arrangement to provide nominal loads on test motor



Wheel Motor Test Rig


Hydraulic Power Supply For Test Rig

Test Rig Schematic Diagram



Sensor List

P1-P3 0-3000 psi
T1-T4 60-200°F
F1-F2 0-3 gpm
C1-C3 0-50 ac Amperes
I1 0-2 inches
G1-G2 0-1 g

Faults Selected

No.	Subsystem	Component	Fault	Detection Method	Installation Method
1	HPSS	High pressure filter	Plugged	Low load side pressure and flow	Install plugged filter
2	HPSS	Accumulator	Loss of charge	Poor transient response	Discharge accumulator
3	HPSS	AC pump drive motor	Open winding	Case vibration and motor current	Remove fuse from one AC phase
4	HPSS	Cooling system	Loss of cooling	Pump motor & fluid temp. increases	Shut off cooling water flow
5	HPSS	Hydraulic pump	Scored crescent housing	Low output pressure/flow. vibration	Use existing "bad" HPSS spare pump
6	HPSS	Hydraulic pump	Internal leakage	Increased flow to tank	Remove internal seal or install broken seal
7	HPSS	Relief valve	Broken spring	Low pressure	Install weak or broken spring
8	Wheel Motor	Hydraulic motor	Broken piston	Vibration or reduced flow	Remove piston or piston seal
9	Wheel Motor	Control valve	Open winding	Change in DP or flow	Relay
10	Wheel Motor	Control valve	Sticking valve	Change in DP or flow	Change control profile in software
11	Wheel Motor	Hydraulic motor	Ruptured line	Tank level change	Tee flow to separate tank
12	Wheel Motor	Resolver	Broken belt/failed resolver	Loss of control signal	Remove encoder belt
13	Wheel Motor	Hydraulic motor	Internal leak	Changes in flow or pressure	External P to T short with variable restriction

Fault Simulation Ranking

No.	Fault	Importance	Complexity	Risk	Rank
1	Plugged HPSS high side filter	4	2	3	12
2	Loss of accumulator charge	4	2	2	10
3	HPSS pump drive motor fault	1	3	3	8
4	Loss of oil cooling	3	1	1	3
5	Scored HP pump housing	2	4	2	10
6	HP pump internal leakage	2	1	1	2
7	Broken relief valve spring	2	3	2	9
8	Damaged piston in wheel motor	3	5	5	13
9	Control valve open winding	3	2	1	5
10	Sticking control valve	2	2	1	4
11	Ruptured pressure supply line	1	1	1	1
12	Motor encoder feedback loss	4	2	1	6
13	Internal leak in wheel motor	4	2	1	6

1 = Most important - 5 = Least important
1 = Simple to implement - 5 = Complex to implement
1 = Low risk - 5 = High risk

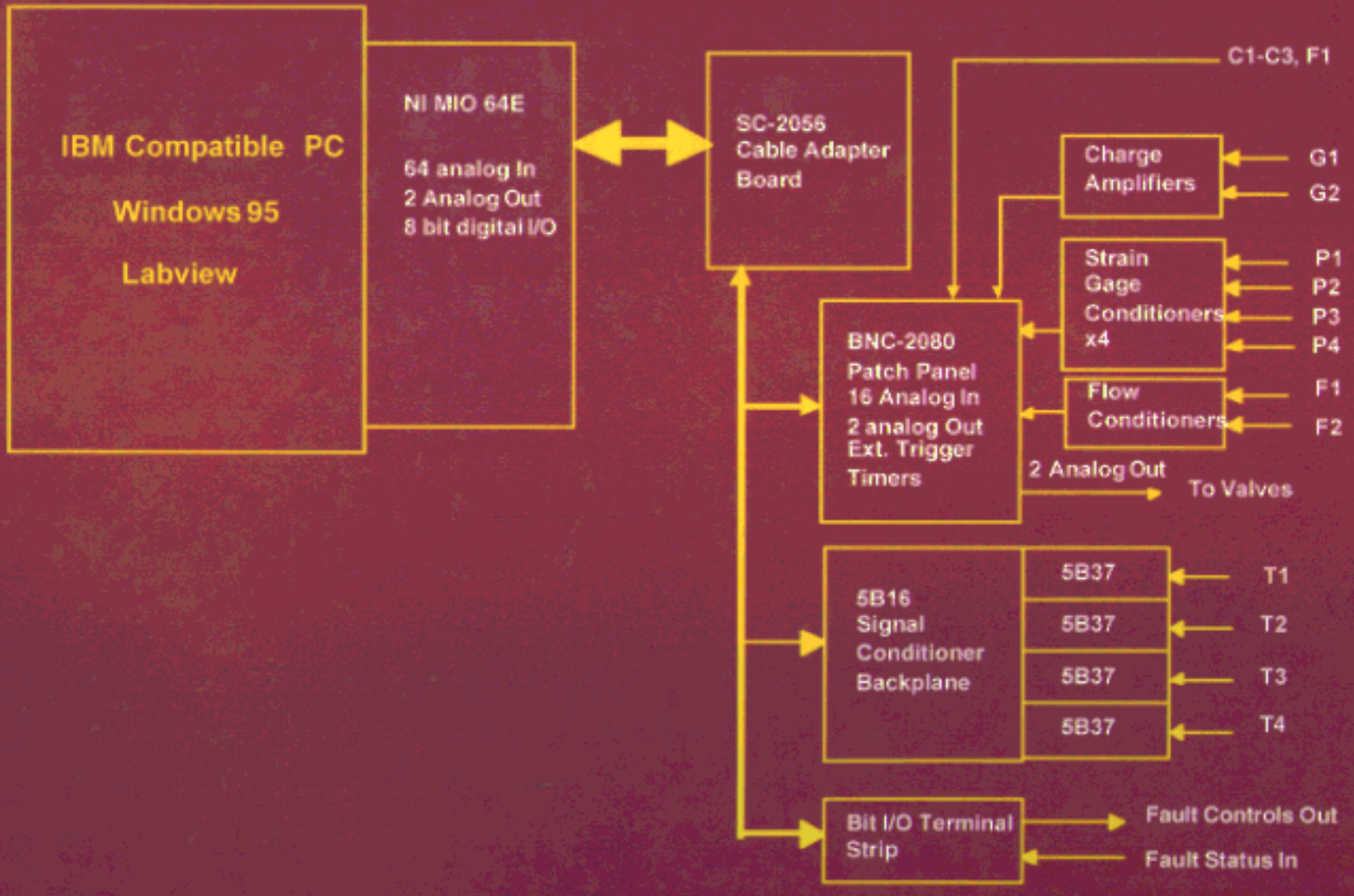
Order of Testing

1. Ruptured pressure supply line
2. HP pump internal leakage
3. Loss of oil cooling
4. Sticking control valve
5. Control valve open winding
6. Motor encoder feedback loss
7. Internal leak in wheel motor
8. HPSS pump drive motor fault
9. Broken relief valve spring
10. Loss of accumulator charge
11. Scored HP pump housing
12. Plugged HPSS high side filter
13. Damaged piston in wheel motor

Sensors

Fault No.	Fault Description	Sensor(s)
1	Plugged HPSS high side filter	Pressure, flow
2	Loss of accumulator charge	Dynamic pressure
3	HPSS pump drive motor fault	Accelerometer, current
4	Loss of oil cooling	Thermocouples
5	Scored HP pump housing	Pressure, flow
6	HP pump internal leakage	Flow
7	Broken relief valve spring	Pressure
8	Damaged piston in wheel motor	Accelerometer, flow
9	Control valve open winding	Pressure, flow
10	Sticking control valve	Pressure, flow
11	Ruptured pressure supply line	Fluid level
12	Loss of wheel motor encoder feedback	Pressure
13	Internal leak in wheel motor	Pressure, flow

Data Acquisition



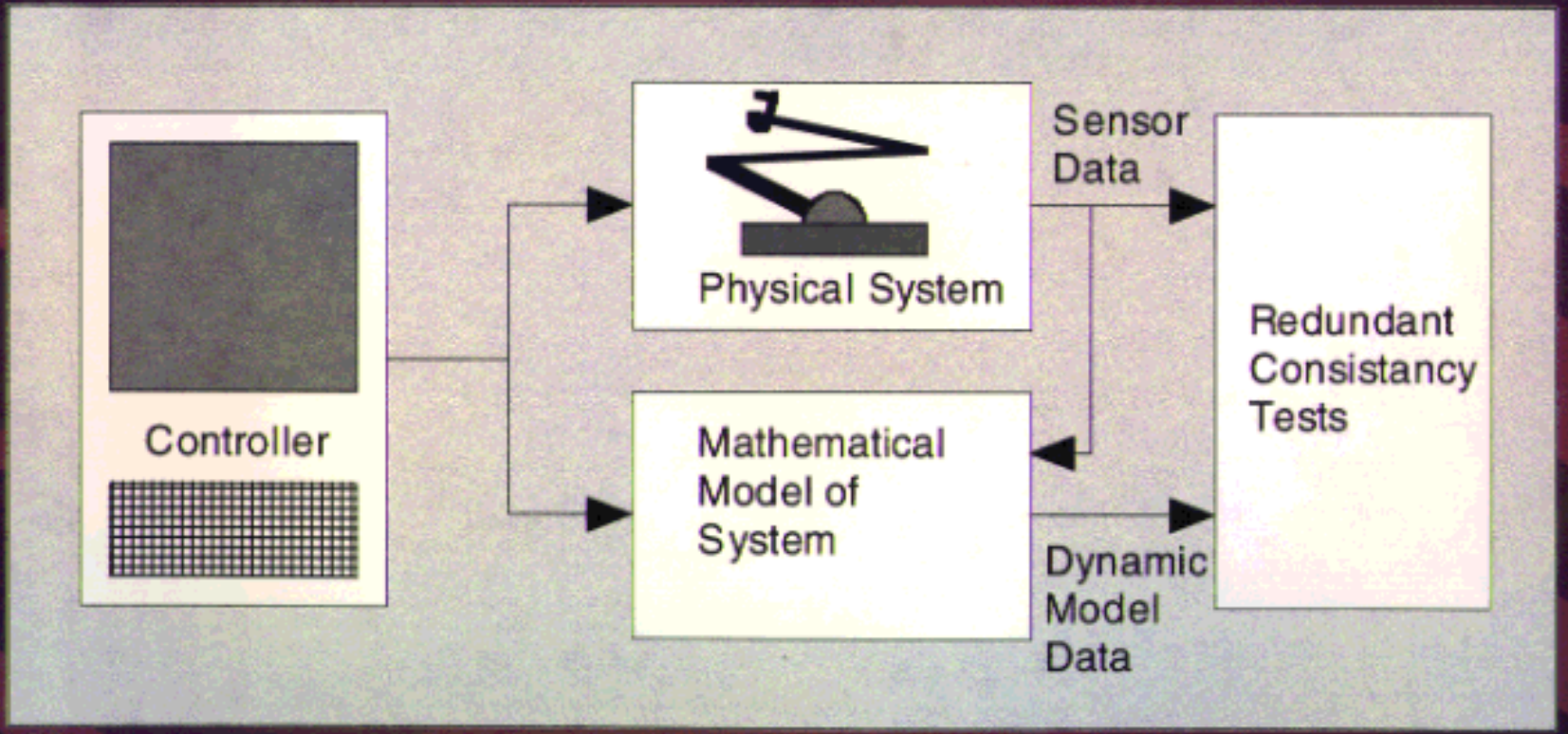
Data Reduction and Fault Detection

- Analytical methods
  - Analytical redundancy
  - Vibration analysis
  - Temperature and pressure tracking
  - Supervisory fuzzy expert system

Analytical Redundancy (AR)

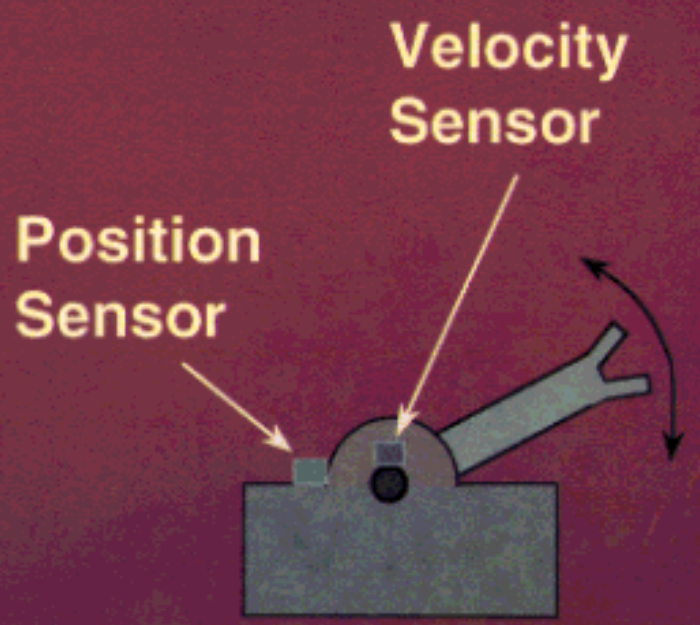
- Model-based fault detection
  - Signals from physical system compared to real-time simulation of system
- Proven formal method
  - Tests against null space of an observability matrix, giving greatest possible number of independent tests
  - Typically uses time history of sensor data to test higher order dynamic response as well as first-order response

Data Flow in AR



AR Example System

- Simple robotic arm
- Single electric motor, position (q) and velocity ($\dot{q}$) sensors
- Acceleration control input (u)



AR Example Tests

- Position reading versus velocity reading
- Position sensor versus computed acceleration
- Velocity sensor versus computed acceleration
- Velocity sensor versus computed jerk

$$\frac{\theta(k+1)-\theta(k)}{\Delta t}=\dot{\theta}(k)$$

$$\frac{\theta(k+2)-2\theta(k+1)-\theta(k)}{\Delta t^2}=u(k)$$

$$\frac{\dot{\theta}(k+1)-\dot{\theta}(k)}{\Delta t}=u(k)$$

$$\dddot{\theta}(k)=\frac{u(k+1)-u(k)}{\Delta t}$$

Summary and Plans

- Fabricate and assemble remaining parts of test rig
- Conduct an initial series of baseline and implanted fault tests
- Interactively conduct tests, data reduction and diagnostic methodology development
  - Adjust subsequent tests based on analysis of data from the initial evaluations