AUTOMATION GOALS

- SIGNIFICANT IMPROVEMENT IN PRODUCTIVITY AND RELIABILITY
- APPLICATION OF ARTIFICIAL INTELLIGENCE METHODS TO GROUND-BASED MONITORING
- ADVANCEMENT OF ARTIFICIAL INTELLIGENCE TECHNOLOGY
AUTOMATION STRATEGY

- ACTIVE INVOLVEMENT OF THE END USER

- INCREMENTAL DEVELOPMENT WITH REGULAR DELIVERIES TO THE END USER

- EMPHASIS ON USABLE, REAL-WORLD PRODUCTS RATHER THAN PROTOTYPE DEMONSTRATIONS
RESEARCH & DEVELOPMENT ACTIVITIES

- AUTOMATED MISSION MONITORING AND ANALYSIS
- INTELLIGENT INPUT DATA MANAGEMENT
- SYSTEM-LEVEL ANALYSIS USING COOPERATING EXPERT SYSTEMS
AUTOMATED MISSION MONITORING AND ANALYSIS

- REAL-TIME MONITORING OF SPACECRAFT AND TELEMETRY
- KNOWLEDGE-BASED ANOMALY ANALYSIS
- COMBINATION OF CONVENTIONAL AUTOMATION AND ARTIFICIAL INTELLIGENCE
- MULTI-MISSION APPLICABILITY
- TWO-YEAR HISTORY OF CONTINUOUS ON-LINE OPERATION
MONITOR/
ANALYZER OF
REAL-TIME
VOYAGER
ENGINEERING
LINK
MARVEL

- FUNCTIONS
  - REAL-TIME MONITORING
  - REAL-TIME KNOWLEDGE-BASED ANALYSIS
  - GENERAL PRODUCTIVITY ENHANCEMENT

- FEATURES
  - DATA DISPLAY AND ARCHIVING
  - AUTOMATED ALARM MESSAGES
  - HIERARCHICAL ORGANIZATION
  - WINDOW ENVIRONMENT
  - MOUSE- AND MENU-DRIVEN OPERATION
  - ON-LINE USER DOCUMENTATION
MARVEL

IMPLEMENTATION

• DISTRIBUTED MULTI-WORKSTATION ENVIRONMENT
  • MESSAGE PASSING FOR INTERPROCESS COMMUNICATION
  • VARIABLE NUMBER OF NODES

• MULTIPLE C PROCESSES PROVIDE STANDARD AUTOMATION
  • PROCEDURAL AND ALGORITHMIC FUNCTIONS
  • USER-INTERFACE FUNCTIONS
  • REAL-TIME SPEED AND PORTABILITY

• EMBEDDED KNOWLEDGE BASES PROVIDE EXPERT REASONING
  • ANOMALY ANALYSIS
  • CORRECTIVE ACTION RECOMMENDATIONS
  • COMPATIBILITY WITH C

• GOAL- AND DATA-DRIVEN REASONING ARE COMBINED IN
  KNOWLEDGE-BASED ANALYSIS MODULES

• LOWER-LEVEL C ALGORITHMS PROVIDE CALCULATIONS NEEDED
  BY THE KNOWLEDGE BASES
MARVEL

ACHIEVEMENTS

• SIMULTANEOUS AUTOMATED MONITORING OF THREE VOYAGER SUBSYSTEMS
  • COMPUTER COMMAND SUBSYSTEM
  • FLIGHT DATA SUBSYSTEM
  • ATTITUDE AND ARTICULATION CONTROL SUBSYSTEM

• KNOWLEDGE-BASED ANOMALY ANALYSIS AND CORRECTIVE RECOMMENDATIONS FOR TWO VOYAGER SUBSYSTEMS
  • COMPUTER COMMAND SUBSYSTEM
  • ATTITUDE AND ARTICULATION CONTROL SUBSYSTEM

• CONTINUOUS ON-LINE OPERATION FOR BOTH VOYAGER SPACECRAFT SINCE AUGUST 1989

• SUCCESSFUL DETECTION OF ALL ANOMALIES
  • IMPROVED ACCURACY
  • IMPROVED TIMELINESS

• SMOOTH TRANSITION FOR POST-ENCOUNTER WORKFORCE REDUCTIONS AND CROSS-TRAINING OF PERSONNEL

• TRANSITION TO TOPEX, GALILEO, AND Craf/Cassini
INTELLIGENT INPUT DATA MANAGEMENT

- MANAGEMENT OF INPUT DATA VOLUMES THAT EXCEED PROCESSING CAPACITY

- COMBINATION OF DECISION THEORY AND KNOWLEDGE-BASED METHODS

- AUTOMATION OF AN IMPORTANT REAL-TIME TRADE-OFF BETWEEN

  AMOUNT OF INPUT PROCESSED

  VS

  TIMELINESS OF OUTPUT
DECISION THEORY FOR MAKING TRADE-OFFS

- UTILITY THEORY AND PROBABILITY ARE USED TO SELECT THE MAXIMUM-VALUE ACTION FROM A SET OF POSSIBLE ACTIONS.

- THE VALUE (V) OF AN ACTION (X) IS DETERMINED WITH A SET OF EVALUATION CRITERIA (i = 1 TO n) AND WEIGHTING FACTORS (W)

\[ V = \sum_{i=1}^{n} w_i v_i(X_i) \]

- DECISION THEORY HAS A HISTORY OF SUCCESSFUL APPLICATION TO MAKING TRADE-OFF DECISIONS IN STATIC ENVIRONMENTS.
DYNAMIC TRADE-OFF EVALUATION

- EXTENDS STATIC TECHNIQUES FOR USE IN REAL-TIME ENVIRONMENTS

- USES DOMAIN KNOWLEDGE TO
  
  - DYNAMICALLY RE-WEIGHT THE EVALUATION CRITERIA TO REFLECT THE DYNAMICS OF THE EXTERNAL ENVIRONMENT.

  - REDEFINE COURSES OF ACTION AS DICTATED BY THE EXTERNAL ENVIRONMENT.

- HAS BEEN APPLIED TO EVALUATING THE TRADE-OFF BETWEEN THE AMOUNT OF INPUT DATA AND THE TIMELINESS OF THE OUTPUT.
EVALUATION OF ANOMALY DETECTION RESULTS

3% ANOMALY DENSITY

% OF ANOMALIES DETECTED

RANDOM DATA ELIMINATION
INCREMENTAL FILTERING
INTELLIGENT DATA MANAGEMENT

COMPUTATIONAL LOAD
EVALUATION OF DATA MANAGEMENT METHODS
3% ANOMALY DENSITY

% OF ANOMALY-RELEVANT DATA PROCESSED

COMPUTATIONAL LOAD

RANDOM DATA ELIMINATION
INCREMENTAL FILTERING
INTELLIGENT DATA MANAGEMENT
SYSTEM-LEVEL ANALYSIS WITH COOPERATING EXPERT SYSTEMS

- CO-ORDINATION OF HIERARCHICAL EXPERT SYSTEMS

- COMBINATION OF DISTRIBUTED COMPUTING AND MULTIPLE USER-INTERFACES
COOPERATING EXPERT SYSTEMS

- EVENT-DRIVEN INFORMATION EXCHANGE
- DEMONS AT SUBSYSTEM LEVEL RESPOND TO SUBSYSTEM ANOMALIES
- DOMAIN KNOWLEDGE AT SUBSYSTEM LEVEL IS USED TO DETERMINE WHICH
  SUBSYSTEM ANOMALIES HAVE POTENTIAL SYSTEM-LEVEL IMPACT
- SUBSYSTEM DEMONS SEND MESSAGES TO SYSTEM-LEVEL KNOWLEDGE BASE
- SYSTEM-LEVEL DEMONS COORDINATE SYSTEM-LEVEL ANALYSIS
MULTIPLE EXPERT SYSTEMS
DISTRIBUTED ARCHITECTURE

DATA MANAGEMENT PROCESS

CCS SUBSYSTEM PROCESS
- REAL-TIME MONITORING
- NONREAL-TIME PRODUCTIVITY ENHANCEMENT FUNCTIONS
- KNOWLEDGE-BASED ANOMALY ANALYSIS
- USER INTERFACE AND DISPLAY PROCESS

AACS SUBSYSTEM PROCESS
- REAL-TIME MONITORING
- NONREAL-TIME PRODUCTIVITY ENHANCEMENT FUNCTIONS
- KNOWLEDGE-BASED ANOMALY ANALYSIS
- USER INTERFACE AND DISPLAY PROCESS

FDS SUBSYSTEM PROCESS
- REAL-TIME MONITORING
- NONREAL-TIME PRODUCTIVITY ENHANCEMENT FUNCTIONS
- KNOWLEDGE-BASED ANOMALY ANALYSIS
- USER INTERFACE AND DISPLAY PROCESS

SYSTEM-LEVEL KNOWLEDGE-BASED ANALYSIS PROCESS
EVENT-DRIVEN RESPONSE

- DEMONS IN THE KNOWLEDGE BASE CONTROL REASONING
  - EVENT-DRIVEN RESPONSE TO ANOMALY CONDITIONS
  - INSTANTIATION OF APPROPRIATE RESPONSE PLANS

- DEMONS ARE ACTIVATED BY THE APPEARANCE OF ANOMALOUS DATA
  - TELEMETRY
  - INFERRED KNOWLEDGE FROM BACKWARD CHAINING
  - OTHER DEMONS

- BACKWARD-CHAINED PRODUCTION RULES PERFORM DIAGNOSIS
  - ANOMALY ANALYSIS
  - RECOMMENDATIONS FOR CORRECTIVE ACTION

- RULES ARE ACTIVATED BY DEMONS
EVENT-DRIVEN RESPONSE

Current channel = E-201
E-201 bit 8 has changed

Current channel = E-202
E-202 bit 6 has changed
E-202 bit 5 has changed

Current channel is a status word.
Apparent anomaly = true.

Perform data corruption check
Subsystem Monitor

Anomaly = HYBIC swap
E-203 bit 6 = 0
Sun intensity level <
sun disacquire gate

Diagnosis = sun sensor degradation.

Anomaly = HYBIC swap
E-203 bit 6 = 0
(Sun intensity level = 0 OR
Sun intensity level = 255)

Diagnosis = sun sensor failure.

Anomaly = HYBIC swap
E-201 bit 3 = 0

Diagnosis = Canopus star tracker problem.

E-201 bit 8 = 0
E-202 bit 6 = 1
E-202 bit 5 = 0

HYBIC pattern is consistent

Event: Prime HYBIC changed at time \( t_1 \)
Event: HYBIC 1 power changed at time \( t_2 \)
Event: HYBIC 2 power changed at time \( t_3 \)

Event: E-200 bit 6 changed at time \( t_4 \)
Event: E-200 bit 3 changed at time \( t_5 \)
E-200 bit 6 \( \leftrightarrow \) E-200 bit 3

Anomaly = HYBIC swap
ISO-valve pattern has changed
\( t_4 < t_1, t_2, t_3 \)
\( t_5 < t_1, t_2, t_3 \)

Diagnosis = second TCAPUF failure.

Event: E-200 bit 7 changed at time \( t_4 \)
Event: E-200 bit 4 changed at time \( t_5 \)
E-200 bit 7 \( \leftrightarrow \) E-200 bit 4

ANTEC \( \rightarrow \) Rule antecedent

CONS \( \rightarrow \) Forward chained consequent

GOAL \( \rightarrow \) Backward-chained goal

Interprocess communication
SUMMARY

- REAL-TIME, REAL-WORLD DEMONSTRATION OF SIGNIFICANT ARTIFICIAL INTELLIGENCE CAPABILITIES
  - INTELLIGENT DATA MANAGEMENT
  - EVENT-DRIVEN COORDINATION OF KNOWLEDGE-BASED DIAGNOSTICS
  - APPROPRIATE RESPONSE TO UNCERTAIN DATA
  - MULTIPLE EXPERT SYSTEMS

- SUCCESSFUL INTEGRATION OF ARTIFICIAL INTELLIGENCE AND CONVENTIONAL AUTOMATION HAS ACHIEVED
  - FULLY-AUTOMATED, REAL-TIME MONITORING AND DIAGNOSIS
  - RECOMMENDATIONS FOR CORRECTIVE ACTION
  - PRODUCTIVITY ENHANCEMENT TOOLS

- DEMONSTRATION OF WORKFORCE REDUCTIONS AND IMPROVED PERFORMANCE