A CONCURRENT ARCHITECTURE FOR REAL-TIME INTELLIGENT PROCESS CONTROL

Jack Park
Visiting Scientist, USAF
Maj. Stephen R. Le Clair, USAF

ABSTRACT

We describe an architecture comprised of three microprocessor-based expert systems, each operating concurrently in a real-time process control environment. This architecture has been applied to the control of an autoclave. Early results are encouraging: successful cure of 256-ply carbon-fiber laminates traditionally requires up to twelve hours of cure time, while the knowledge base created for the concurrent architecture has successfully cured the same laminates repeatably in three hours.

Two of the expert systems are implemented on M68000-based co-processors on an IBM PC-class computer, and the third expert system is implemented in the pc itself. Each expert system is a version of the FORTH-based EXPERT-5, running a qualitative process shell language (QPA), and a knowledge base suited to the process control task. The pc-based expert system serves as a blackboard monitor, controlling communications between the expert systems themselves, and between process sensors, autoclave controls, and the expert systems.

This work is supported by the U.S. Air Force, MLT and FIG laboratories, Wright-Patterson AFB.

SYSTEM OVERVIEW

A real-time process control system has been constructed and tested with a small autoclave at the Materials Laboratory at Wright Patterson AFB. This process controller applies qualitative process theory (QP-Theory) [Forbus85] to the task of determining current states of the process and achieving goals (the cure of a carbon-fiber laminate).

The process controller architecture divides the task of issuing appropriate commands to the autoclave into two separate subtasks:

1- parsing the flow of input data
2- determining the next appropriate command and issuing it

Parsing is the name of the subtask of reading input "sentences" from the data acquisition card and determining which states (e.g. processes) are active. This amounts to determining if the preconditions for a given process are active as evidenced by the input stream. A process is represented in SENSOR FUSION as a frame [Minsky75], with preconditions and effects as primary slots.

Thinking - determining the next appropriate command and issuing it is the subtask of comparing current goals to the current state defined by the parser, and finding an appropriate action through means-ends-analysis [ERNST69].

A blackboard [HAYES-ROTH85] serves as the vehicle by which the parser and thinker communicate with each other and with the outside world (autoclave). The three subtasks - parsing, thinking, and blackboard management - are assigned to separate computers operating concurrently on a PC bus. The PC serves as the blackboard monitor, collecting data from the data acquisition board, sending commands to the autoclave, passing information between parser and thinker, and communicating with the user at the terminal. The parser and thinker each are separate M68000-based coprocessors [HALLOCK85] with one megabyte of memory.

Software is implemented in FORTH on each processor. The underlying shell is EXPERT-5 [PARK85] which implements a FORTH-based production system akin to OPS5 [BROWNSTONE85], together with tools for frame representation, and a blackboard.

SOME PRELIMINARY RESULTS

The two figures show the results of a cure cycle. One figure shows a typical cure cycle with the QPA system, while the other figure shows a QPA-driven cure as compared with an industry-typical cure cycle; QPA achieves full cure in about three hours as compared to a typical ten to twelve hours for the same cure using the industry time-temperature cure cycle.

These results are preliminary, but indicative of the capabilities of QPA. The cure cycles are repeatable, and physical properties of the components cured under control of QPA are comparable to those achieved with the industry-typical cure cycle. As such, we believe the results achieved thus far are encouraging, and continued exploration of the capabilities of QPA are under way.

REFERENCES

[BROWNSTONE85] Brownston, L., Farrell, R. Kant, E. and Martin, N.: PROGRAMMING EXPERT SYSTEMS IN OPS5; 1985, Addison-Wesley.

[ERNST69] Ernst, G., and Newell, A.; GPS: A CASE STUDY IN GENERALITY AND PROBLEM SOLVING; 1969, Academic Press.

[FORBUS85] Forbus, Kenneth D.; "Qualitative Process Theory" in Bobrow, Daniel G., ed, QUALITATIVE REASONING ABOUT PHYSICAL SYSTEMS; 1985, MIT Press.

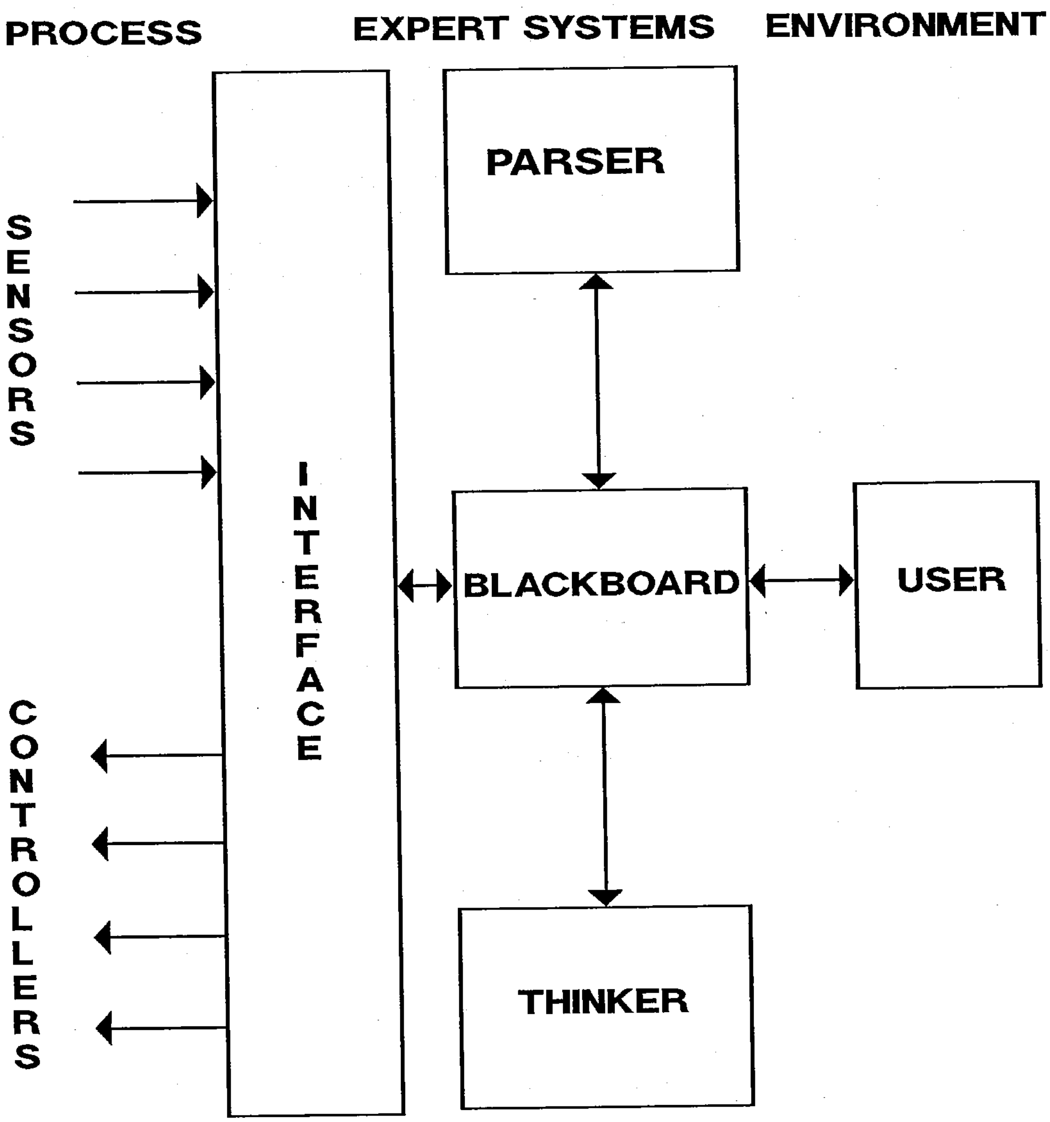
[HALLOCK85] Hallock Systems Company; PRO-68 owners manual, 1985.

[HAYES-ROTH85] Hayes-Roth, B.; "A Blackboard Architecture for Control" in Artificial Intelligence 26 (1985), pp 251-321.

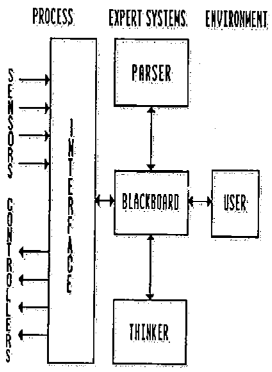
[MINSKY75] Minsky, Marvin; "A Framework for Representing Knowledge" in Winston, P. ed, THE PSYCHOLOGY OF COMPUTER VISION; 1975, McGraw-Hill.

[PARK85] Park, Jack; EXPERT-5 User's Manual; unpublished manuscript.

QUALITATIVE REASONING



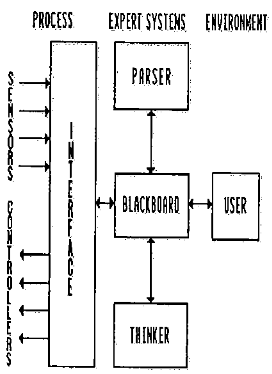
PARSER



TRANSFORMS INPUT DATA INTO:

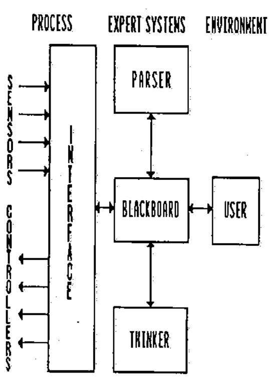
- **STATE OF PROCESS**
- **TRAJECTORY OF PROCESS**

BLACKBOARD



**PROVIDES UNIFORM "PLACE"
FOR ALL KNOWLEDGE SOURCES
(e.g. PARSER & THINKER)
TO COMMUNICATE**

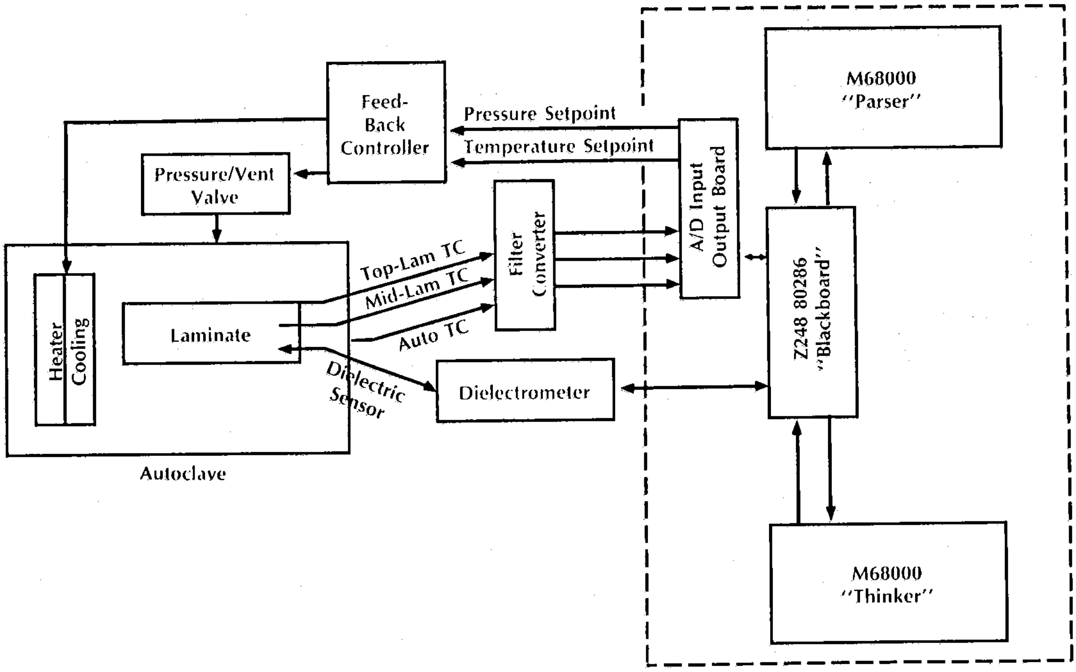
THINKER



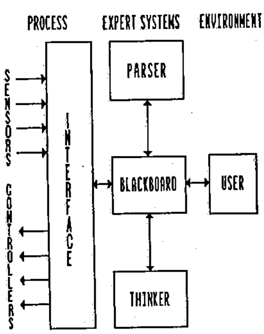
**DETERMINES APPROPRIATE
RESPONSE (e.g. CONTROL COMMAND)
BASED ON DIFFERENCE BETWEEN**

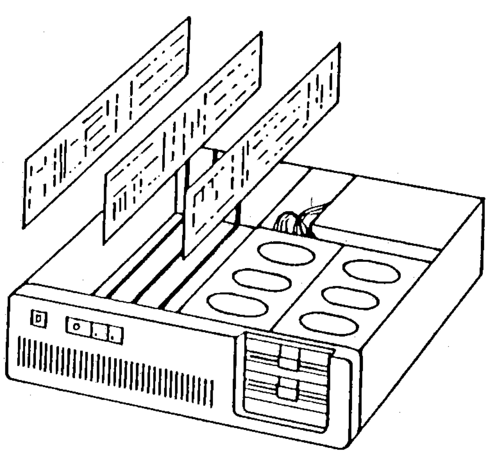
- **CURRENT STATE AND TRAJECTORY (PARSE)**
- **CURRENT GOALS (PLAN)**

SYSTEM CONFIGURATION

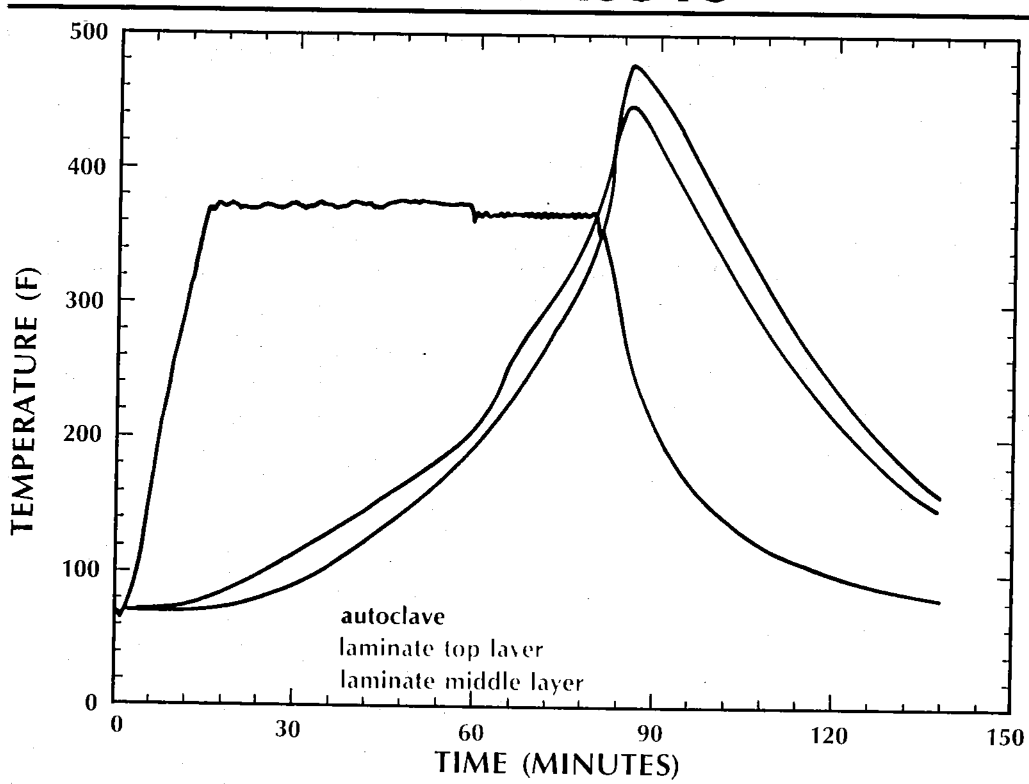


HARDWARE





256-PLY 1034C



CURE CYCLES SHORTENED CONSIDERABLY