MINE 432
Industrial Automation and Robotics

Part 3, Lecture 3
Expert Systems Applications in Mining

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MINE 432 - Industrial Automation and Robotics
Today’s Topics

Applications of expert systems in mining engineering

Introduction to CLIPS

GCOS (Grinding Circuits Optimization Supervisor)
Applications of Expert Systems in Mining Engineering
Engineering Tasks

Interpretation
Diagnosis
Monitoring
Prediction
Planning
Design
Optimization
The size of the solution space and the required search effort are tightly linked to nature of the problem and impose limitations on the choice of inferencing method.
Modes of Using Expert Systems
# Control Expert Systems Applied to Grinding Circuits

<table>
<thead>
<tr>
<th>Site</th>
<th>Circuit type</th>
<th>Task</th>
<th>Development tool</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dome Mine, Ontario, Canada</td>
<td>rod mill/ball</td>
<td>control</td>
<td>Comdale/C</td>
<td>Eggert and Benford 1994</td>
</tr>
<tr>
<td>Wabush Mine, Labrador, Canada</td>
<td>autogenous/spiral</td>
<td>monitoring and control</td>
<td>Comdale/C</td>
<td>McDermott et al. 1992</td>
</tr>
<tr>
<td>Les Mines Selbaie, Quebec, Canada</td>
<td>semi-autogenous grinding (SAG)</td>
<td>on-line optimization</td>
<td>Comdale/C</td>
<td>Perry and Hall 1994</td>
</tr>
<tr>
<td>Brenda Mines Ltd., Canada</td>
<td>rod mill/ball mill</td>
<td>control</td>
<td>Superintendent</td>
<td>Spring and Edwards 1989</td>
</tr>
<tr>
<td>Kiruna LKAB Concentrators, Sweden</td>
<td>secondary grinding. pebble mills</td>
<td>control</td>
<td>N/A</td>
<td>Samskog et al. 1995</td>
</tr>
<tr>
<td>Mexicana de Cobre, La Caridad Unit, Sonora, Mexico</td>
<td>primary ball mills/hydrocyclones</td>
<td>control</td>
<td>N/A</td>
<td>Herbst et al. 1995</td>
</tr>
</tbody>
</table>
A real time expert system was implemented by Brenda Process Technology to control one of their rod mill/ball mill grinding circuits. SUPERINTENDENT, written in Pascal, was used as the expert system shell and is based on a supportive control package called ONSPEC; both were supplied by the Heuristics Inc. Brenda developed and encoded the knowledge base, GRINDX, which contains rules to control the #2 grinding circuit.
An expert system was developed by Comdale Technologies with the objective of increasing circuit tonnage. The grinding circuit knowledge base was written using the Comdale/C expert system shell to supervise the Distributed Control System (DCS). The knowledge base consisted of simple rules with an O-A-V structure to represent process information and also fuzzy rules to implement a fuzzy logic control scheme.
An expert system was added to the automatic control system in May 1992 to optimize the A1 closed grinding circuit by manipulating the set-points of existing PI control loops. The knowledge base containing (fuzzy) control rules is run under the Comdale/C shell. The operating expertise, extracted from interviews with plant control personnel, was represented by 188 rules and 69 fuzzy sets.
Wabush Mine

The system was developed using the Comdale/C shell. The knowledge base included 76 rules, 35 fuzzy sets to recognize process states, 19 fuzzy sets for control actions, 25 fuzzy sets to identify trends and 24 variables monitored for time variation. The rules and fuzzy sets embody the operating and control expertise of Wabush Mine personnel.

**IF** mill power draw is high and trending upward fast and recirculating density is not too high and not trending upward and recirculating sump level is too high and trending upward

**THEN**

reduce mill feed water by small amount
MBEC (Model-Based Expert Control) systems have been installed for dynamic optimization of the three old pebble mill circuits and the new concentrator.
The control strategy utilizes knowledge and information that originate from a variety of resources: (1) heuristics based on practice of the best operator, (2) process models to estimate variables that cannot be measured on-line and (3) neural networks for processes that cannot be modeled accurately because of their inherent complexity.
Introduction to CLIPS
CLIPS is an open source expert system shell which is available for free. Complete information, helps and manuals can be found here:

http://clipsrules.sourceforge.net/
Introduction

• Expert System Tool

• Complete environment for building rule/object based Expert Systems

• Developed by Software Technology Branch, at NASA’s Johnson Space Centre (1985)

• Released 1986

• Developed to address shortcomings of LISP
  • Low availability of LISP on computers
  • High cost associated with LISP tools and hardware
  • Poor integration with other languages
CLIPS Shell

FACT LIST
(CONTAINS DATA)

KNOWLEDGE BASE
(CONTAINS RULES)

INFERENACE ENGINE
(CONTROLS EXECUTION)
CLIPS Shell (Cont’d)

• Fact list and instance list is the global memory for data
  • Facts are data that designate relation or information such as (is-animal duck) or (this is a test) or (animals duck horse cow chicken)

• Knowledge base contains all the rules
  • Rules applied on facts in the form of IF-THEN rules

• Inference engine controls the execution of rules
  • Search in the Inference Engine uses forward-chaining and rule prioritization
CLIPS Shell (Cont’d)

• CLIPS has pattern matching abilities (the Rete Algorithm)
• Extended math functions
• Conditional tests
• Object Oriented programming (COOL: Clips Object-Oriented Language) with abstraction, Inheritance, Encapsulation, Polymorphism, Dynamic Binding
Key Features

• Designed using C programming language providing:
  • High portability
  • Low cost
  • Easy integration with external systems

• May be called from a procedural language, or may call procedural code

• Designed for integration with languages such as C, C++, FORTRAN, Java and Ada
Key Features

• Multi-paradigm language that supports rule-based, object-oriented and procedural programming
• CLIPS supports only forward chaining rules
• Originally provided support for rule-based programming
• Represents human knowledge in 3 ways:
  • Rules for experience based, heuristic knowledge
  • Deffunctions and generic functions for procedural knowledge
  • OOP also for procedural knowledge
Notation/Constructs

• Arithmetic Operations
  • Addition (+ 6 3 2)
  • Subtraction (- 6 3 2)
  • Multiplication (* 6 3 2)
  • Division (/ 6 3 2)
Notation/Constructs

- Facts – data or information to reason
  
  (person (name “John Q. Public”)  
  (age 23)  
  (eye-color blue)  
  (hair-color black))
Notation/Constructs

• Deftemplate
  
  (deftemplate person
    (slot name)
    (slot age)
    (slot eye-color)
    (slot hair-color))
Notation/ Constructs

- Assert

  (assert (person (name "John Q. Public")
          (age 23)
          (eye-color blue)
          (hair-color black)))
Deffacts
(deffacts people
  (person (name "John Q. Public") (age 23)
   (eye-color blue) (hair-color black))
  (person (name "Jane Q. Doe") (age 26)
   (eye-color blue) (hair-color brown)))
Notation/Constructs

• Defrule

(deftemplate emergency (slot type))
(deftemplate response (slot action))

(defrule fire-emergency
  (emergency (type fire))
  =>
  (assert (response (action activate-sprinklers))))
General format for Defrule
(defrule <rule_name>
  <patterns>
  =>
  <actions>

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Executing a CLIPS program

- Open Clips editor/ Notepad
- Add rules to knowledge base
- Add facts to global memory
- Load file
- Reset file
- Execute run command
A Simple Sample Program

(defrule ideal-duck-bachelor
  (bill big ?name)
  (feet wide ?name)
=>
(printout t "The ideal duck is " ?name crlf))

(deffacts duck-assets
(bill big Dopey)
(bill big Dorky)
(bill little Dicky)
(feet wide Dopey)
(feet narrow Dorky)
(feet narrow Dicky))
A Few Variants of CLIPS

- FuzzyCLIPS
- AGENT CLIPS
- DYNACLIPS
- KnowExec
- CAPE
- PerlCLIPS
- wxCLIPS
- EHSIS
GCOS
Grinding Circuits Optimization Supervisor
Grinding Optimization Problem

```
Problem Formulation

Experimental Design

Plant Data Collection

Sample Analysis

Model Structure Definition

Mass Balance

Good Data?

Parameters Estimation

Model Validation

Acceptable Predictions?

Simulation

YES

YES
```
Integration of Grinding Analysis and Simulation Tools with ES Environment
GCOS Modular Structure

Grinding Domain Knowledge
- BALL MILL
- HYDROCYCLONE
- MODSIM
- CIRCUITS

Auxiliary Functions
- MAIN
- TEMPLATES
- FUNCTIONS
- QUERY
- INITIALIZATION
- CONCLUSION
- RESET
Ball Mill Parameters

Initial derivations are parameters that must be entered by the user.

Intermediate derivation means that the GCOS asserts the data in knowledge base.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Type</th>
<th>Unit</th>
<th>Derivation</th>
<th>Constraint</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discharge type</td>
<td>Symbolic</td>
<td>-</td>
<td>Initial*</td>
<td>Overflow, diaphragm</td>
</tr>
<tr>
<td>Mill length</td>
<td>Numeric</td>
<td>m.</td>
<td>Initial</td>
<td>&lt;= 9 m.</td>
</tr>
<tr>
<td>Mill diameter</td>
<td>Numeric</td>
<td>m.</td>
<td>Initial</td>
<td>&lt;= 6 m.</td>
</tr>
<tr>
<td>Laboratory work index</td>
<td>Numeric</td>
<td>kWh/t</td>
<td>Initial</td>
<td>&gt; 0</td>
</tr>
<tr>
<td>Operating work index</td>
<td>Numeric</td>
<td>kWh/t</td>
<td>Initial</td>
<td>&gt; 0</td>
</tr>
<tr>
<td>Critical speed</td>
<td>Numeric</td>
<td>rpm</td>
<td>Intermediate</td>
<td>&gt; 0</td>
</tr>
<tr>
<td>Media type</td>
<td>Symbolic</td>
<td>-</td>
<td></td>
<td>Ball, slug</td>
</tr>
<tr>
<td>Make-up ball size</td>
<td>Numeric</td>
<td>mm.</td>
<td>Initial</td>
<td>&gt; 0</td>
</tr>
<tr>
<td>Liner wear rate</td>
<td>Numeric</td>
<td>kg/kWh</td>
<td>Initial</td>
<td>&gt; 0</td>
</tr>
<tr>
<td>Ball wear rate</td>
<td>Numeric</td>
<td>kg/kWh</td>
<td>Initial</td>
<td>&gt; 0</td>
</tr>
<tr>
<td>Energy consumption</td>
<td>Symbolic</td>
<td>-</td>
<td>Intermediate</td>
<td>Good, ok, bad</td>
</tr>
<tr>
<td>Operation mode</td>
<td>Symbolic</td>
<td>-</td>
<td>Initial</td>
<td>Wet, dry</td>
</tr>
<tr>
<td>Circuit type</td>
<td>Symbolic</td>
<td>-</td>
<td>Initial</td>
<td>Open, closed</td>
</tr>
</tbody>
</table>
# Hydrocyclone Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Type</th>
<th>Unit</th>
<th>Derivation</th>
<th>Constraint</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of operating cyclones</td>
<td>Numeric</td>
<td>-</td>
<td>Initial</td>
<td>&gt; 0</td>
</tr>
<tr>
<td>Cyclone pressure</td>
<td>Numeric</td>
<td>kPa</td>
<td>Initial</td>
<td>&gt; 0</td>
</tr>
<tr>
<td>Feed flow rate</td>
<td>Numeric</td>
<td>t/h</td>
<td>Initial</td>
<td>&gt; 0</td>
</tr>
<tr>
<td>CUF density (% solids)</td>
<td>Numeric</td>
<td>%</td>
<td>Initial</td>
<td>0-100</td>
</tr>
<tr>
<td>Corrected cut size, $D_{50c}$</td>
<td>Numeric</td>
<td>μm</td>
<td>Initial</td>
<td>&gt; 0</td>
</tr>
<tr>
<td>Separation sharpness, m</td>
<td>Numeric</td>
<td>-</td>
<td>Initial</td>
<td>&gt; 0</td>
</tr>
<tr>
<td>Water split, $R_w$</td>
<td>Numeric</td>
<td>%</td>
<td>Initial</td>
<td>0-100</td>
</tr>
<tr>
<td>Underflow discharge type</td>
<td>Symbolic</td>
<td>-</td>
<td>Initial</td>
<td>Spray, semi-rop, rope</td>
</tr>
<tr>
<td>Classification arrangement</td>
<td>Symbolic</td>
<td>-</td>
<td>Initial</td>
<td>Single stage, multi-stage</td>
</tr>
<tr>
<td>Ore constitution</td>
<td>Symbolic</td>
<td>-</td>
<td>Initial</td>
<td>Single species, multi-species</td>
</tr>
</tbody>
</table>
GCOS Structure
GCOS Structure

Have you fitted Plitt's model to the classification data?

YES

Have you optimised the fit?

YES

Have you obtained a positive $R_f$?

YES

Is the optimised fit satisfactory?

YES

Calculate $R_f$ from the cyclone overflow and underflow solids flow rates and % solids and estimate $d_{50c}$ and $m$

NO

Perform a circuit survey to collect required classification data

NO

Have you got the measured raw data such as the cyclone overflow, cyclone underflow size distributions, flow rates, etc.?

YES

Optimise fit

Fit Plitt's model to data

NO

UNREACHABLE
GCOS Structure

Does there exist a hump or plateau in the measured classification curve?

YES

Do there exist heavy and light minerals in the ore?

YES

Individual behaviour study

NO

Did you mass balance the raw classification data?

YES

Repeat sampling

NO

Do mass balance before fitting Plitt’s model to the data

NO

Repeat sampling

NO

Try a fish hook model such as one by Finch [1983]

NO

Did you mass balance the raw classification data?

YES

Repeat sampling

NO

Do mass balance before fitting Plitt’s model to the data
### Circuit Data

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circuit type</td>
<td>Closed</td>
</tr>
<tr>
<td>Grinding operation mode</td>
<td>Wet</td>
</tr>
<tr>
<td>Discharge mechanism</td>
<td>Overflow</td>
</tr>
<tr>
<td>Diameter inside liners (m)</td>
<td>~3.5</td>
</tr>
<tr>
<td>Length inside liners (m)</td>
<td>~5.2</td>
</tr>
<tr>
<td>Mill speed (%CS)</td>
<td>N/A</td>
</tr>
<tr>
<td>Ball top size (mm)</td>
<td>76</td>
</tr>
<tr>
<td>Ball material</td>
<td>Steel</td>
</tr>
<tr>
<td>Ore specific gravity</td>
<td>N/A</td>
</tr>
<tr>
<td>Laboratory work index (kWh/t)</td>
<td>N/A</td>
</tr>
<tr>
<td>Operating work index (kWh/t)</td>
<td>N/A</td>
</tr>
<tr>
<td>$F_{80}$ ($\mu$m)</td>
<td>~212</td>
</tr>
<tr>
<td>Installed motor power (kW)</td>
<td>N/A</td>
</tr>
<tr>
<td>Power draw (kW)</td>
<td>N/A</td>
</tr>
</tbody>
</table>
CONCLUSIONS

The system reached to the following conclusions:

- Decrease make-up or top ball size by 13 mm (0.5 inch). This can be achieved using a blend of make-up balls. Test the effect of this change by NGOTC before real plant exercise.

=>

The current consultation session is terminated.
Would you like to start a new session? (y/n)
=> n
Questions?