Application of Intelligent Control to Material Circulation in Advanced Life Support Systems

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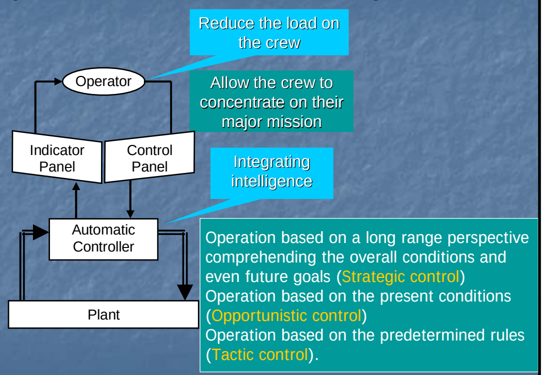
Background (1/2) ALSS?

- An Advanced Life Support System (ALSS) is a life support system (LSS) for accommodating prolonged missions far from Earth.
- It is distinguished from an LSS for International Space Station (ISS) by
  - Food production,
  - Biological processing in addition to physicochemical processing,
  - Resource recovery by recycling human waste and inedible crop portions.
- Typical missions assumed include manned Mars exploration,
  - which is 150 days for the outward trip, 619 days for the Mars stay, and 110 days for the return trip for a total mission of 879 days. (Hoffman and Kaplan, NASA's Reference Mission for Human Exploration of Mars).

Background(2/2) Operation of an ALSS

- An ALSS, a complex and large-scale system, is hard for a small crew to maintain on their own. In order for the crew to concentrate on their major missions, it is essential that intelligence be integrated into the ALSS supervision and control system.
- Moreover, the signal time delay and the bandwidth limitations make remote support from Earth difficult to immediately implement in an ALSS operated far from Earth. This also encourages an autonomous supervision and control system.

Supervision and control system

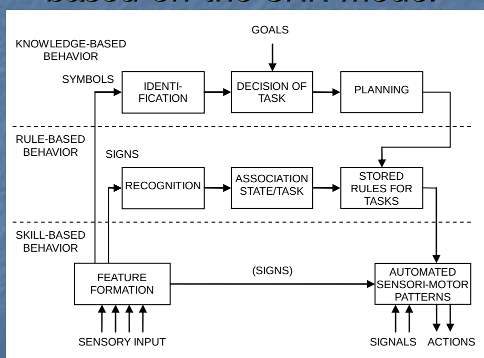


Objective

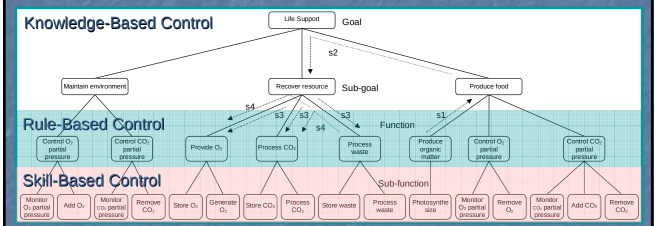
- This study discusses applying intelligent control based on the SRK model to the supervision and control system of an ALSS.

Intelligence？
1. Potential to learn from experience, and potential to memorize knowledge acquired therein,
2. Potential to adapt to new conditions and address them,
3. Potential to think conceptually and solve problems by inference.

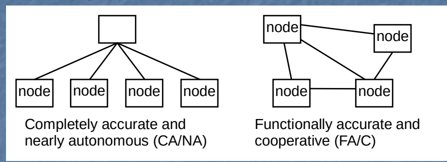
Concept of the intelligent control based on the SRK model



Functional structure of the ALSS



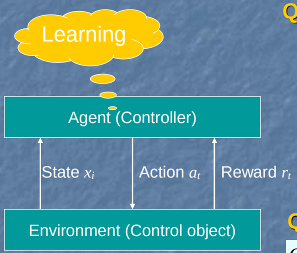
Rule-based control (1/2)
Type of distributed control



CA/NA: The given problem is divided into sets of sub-problems completing within each processing node (Goal-driven problem solving).

FA/C: Each processing node attempts to solve the given problem based on incomplete input data in parallel, cooperating to derive a compatible solution as a whole (Data-driven problem solving).

Rule-based control (2/2)
Reinforcement Learning



Q-Table

	on	off
x_1	0	0.1
x_2	-0.1	0
·		
x_i	0.1	0

Q-Learning

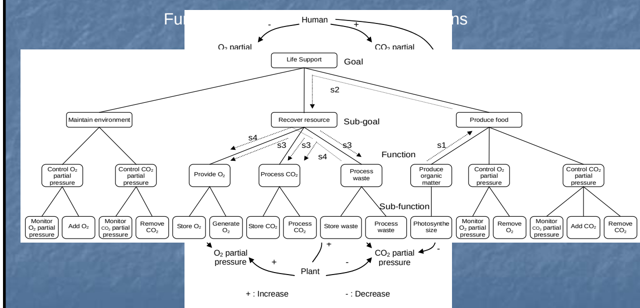
$$Q(x_t, a_t) = (1-\alpha) Q(x_t, a_t) + \alpha\left(r_t + \gamma \max_{a_k} Q(x_{t+1}, a_k)\right)$$

Discount Rate

Learning Rate

Knowledge-based control (1/3)
Conceptual model

Conceptual model of the ALSS



Knowledge-based control (2/3)
Description of the conceptual model

Conceptual model is described in IF-THEN conditional statements that are fuzzy control rules.

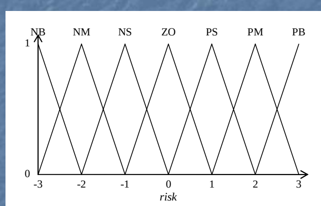
Operation of the solid waste processor

R_i: If x_1 is A_{i1} and x_2 is A_{i2} and x_3 > W3_W then p is B_i, $i = 1,2,\cdots 13$

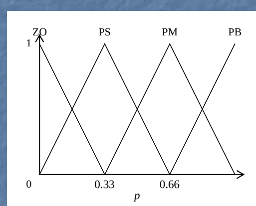
Fuzzy label of p		CO_2 Tank A_{i2}						
		NB(-3)	NM(-2)	NS(-1)	ZO(0)	PS(1)	PM(2)	PB(3)
O_2 Tank A_{i1}	NB(-3)							
	NM(-2)							
	NS(-1)							
	ZO(0)	PS	ZO					
	PS(1)	PM	PS	ZO				
	PM(2)	PB	PM	PS	ZO			
	PB(3)	PB	PB	PM	PS			

NB : Negative Big, NM : Negative Medium, NS : Negative Small,
ZO : Zero, PS : Positive Small, PM : Positive Medium, PB : Positive Big
The label of the fuzzy set corresponds to risk level in ().

Knowledge-based control (3/3)
Fuzzy variables



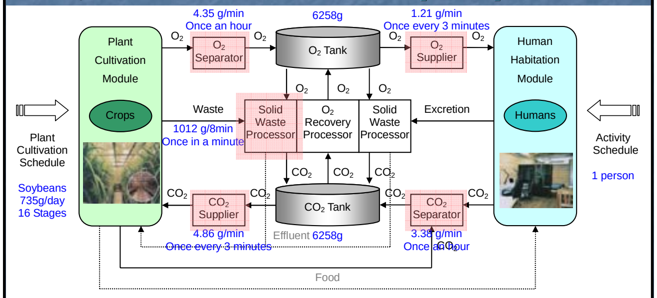
Fuzzy variables for the risk level



Fuzzy variables for the sequence start probability of the solid waste processor

Material circulation systems of the ALSS

Only substances related to the circulation of O_2 and CO_2 are modeled



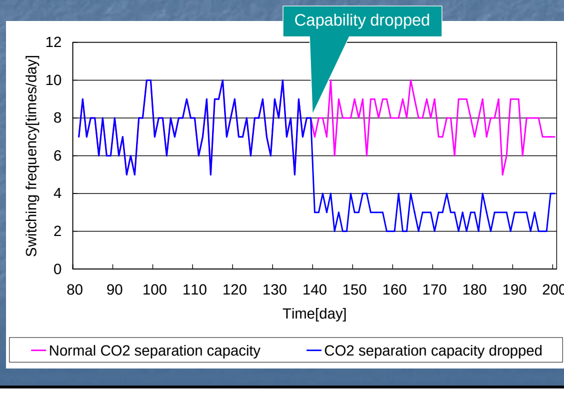
Evaluation of the intelligent control

Rule-Based control : Case where the capability of the CO_2 separator declines

Knowledge-Based control : Case where the crop sequence cultivation schedule is changed

Case of capability deterioration (1/2)

Fluctuations of the switching frequency of the CO_2 separator

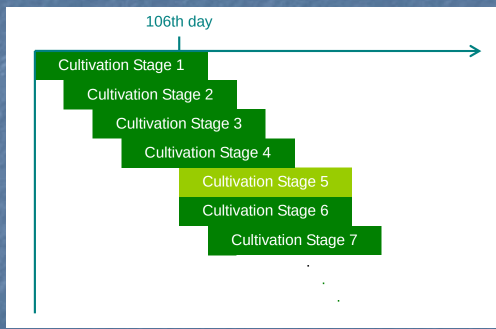


Case of capability deterioration (2/2)

Averages of on/off switching frequency and reward acquisition frequency of the CO_2 separator

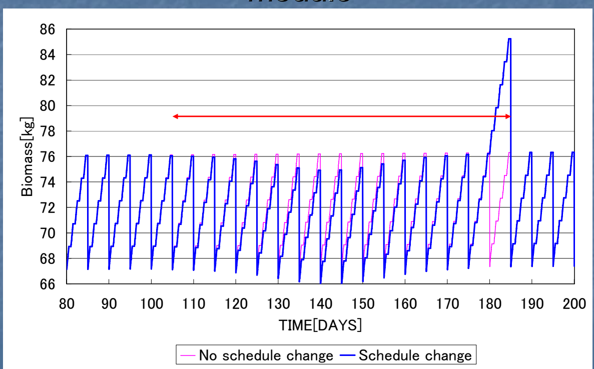
Term	Normal CO_2 separation capacity		CO_2 separation capacity dropped to 50%	
	On/off Switching Frequency	Reward Acquisition Frequency	On/off Switching Frequency	Reward Acquisition Frequency
days	times/day	times/day	times/day	times/day
81-140	7.57	0.40	7.50	0.42
141-200	8.02	0.28	2.87	0.83

Change of the crop sequence cultivation schedule

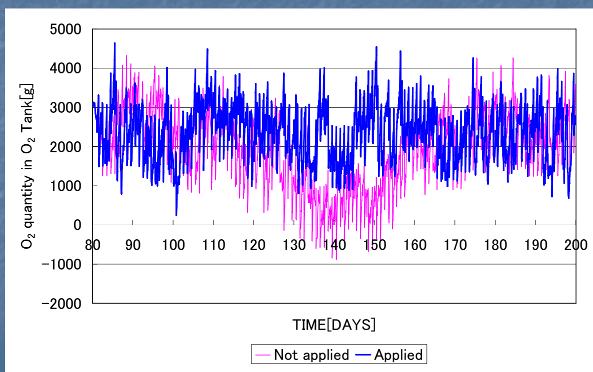


Change of the crop sequence cultivation schedule causes the temporary decrease in O_2 production, CO_2 consumption, and waste generation.

Change of biomass in plant cultivation module



Change of oxygen in the O_2 tank



Amplitudes of substance fluctuation in the tank

Knowledge-Based Control	O_2 Tank [g]	CO_2 Tank [g]
Not applied	5439	5062
Applied	4568	4565

Conclusions

- When the capability of the CO_2 separator declines 50%, the results suggest that rule-based control using Reinforcement Learning enables a new operation procedure when the environment changes.
- When the crop sequence cultivation schedule is changed, the results suggest that the addition of knowledge-based control using fuzzy inference for rule-based control enables designing of the operation schedule of the solid waste processor in an unknown environment.
- Using the intelligent control based on the SRK model allow us to implement long-term strategy planning in an unknown environment as well as short-term environmental change, and the simulation results were shown as an example.
- We would like to study the application of this method to other cases in the future. Especially, it is necessary to extend the conceptual model to other processors.