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Multiple Sensor Fusion and Motion Control of Snake Robot Based on Soft-computing

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1. Introduction

There are many circumstance limits to human like extreme radioactivity, temperature, chemical toxicity, pressure and so on. But, we need to detect and research region for making our sure safe and state. During long time, human have made a robot that have multi-joint biped robot and mobile robot using wheels. And now, that is developing but it still has some problem that is occurred by condition of the ground. Wheel structure is more adaptive to make high speed drive on flat ground and more efficiency to control the drive than other robot. But if it is on the non-flat ground or sandy road, wheel-based drive is not efficient way(Masashi S. et al, 2002). Also biped robot has wonderful adaptation to ground better than wheel-based mobile robot. Considering the condition of the rough ground, multi-joint biped robot that have no running gear like the snake robot have more adaptive than wheel-based robot(K. Dowling, 1999; Honda Motor Co., 1996). If human make a moving robot operate like snake, this snake robot can solve the big problem that is the saving survivor, examination of harmfulness material in the dangerous situation like disaster(a earthquake, explosion and fire)(K. Dowling, 1999). Also it has a good adaptability and moving ability to use widely in difficult situation like researching of dangerous surrounding and medical part(K. Dowling, 1999; S. Hirose, 1993; S. Hirose, 1990; M. Nilsson, 1998). It is just like toy if robot merely operates a joint for driving. Human can recognize their surround using by the five senses. For it can be intelligence robot, robot must have independent sensors. It is possible to judge by comparing the information get through the sensor with the own information. Surely robot have to do that judge(Wako T., 2001; Ren C. Luo, 2002). In this paper, by using the sensors that is worn the snake robot, we can recognize our surround and can reason a suitable act by the sensor information, and we can materialize the snake robot by real movement for real-time. In this research, we realize the intelligence snake robot that is copied from biological snake and that robot can judge intelligently about their circumstance. Surely, this robot can execute their mission by intelligence judging.

2. Character and Structure of Snake Robot

2.1 Movement Method of Snake

Before the study about intelligence snake robot, first we have to know how real-snake move. There are 4 way to move, 'Lateral undulatory motion', 'Rectilinear motion', 'Concertina motion' and 'Side-winding'(K. Dowling, 1999; S. Hirose, 1993; S. Hirose et al, 1990; J. Gray et

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al, 1950; B. C. Jayne, 1986; H. Lissmann, 1950; B.C. Jayne, 1988). Lateral undulatory motion is most general way of moving snake(Figure 1). This way use a configuration or things of the ground. Concertina motion means that sake bend itself like accordion with pressing down the ground in order to move front side(Figure 2). Side-winding means that it moves with contacting ground of two part of a snake when the back side of snake instantly stops moving(Figure 3). The fore part is moving to upper side and front. After this, the back side also moves same as the front. Rectilinear motion is like this(Figure 4). First, the snake put their scale into a ground and they push up their inner body to front side. Next, they pull over their skin.

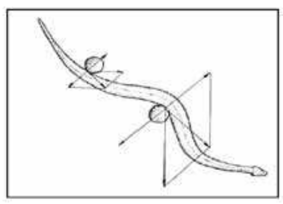

Figure 1. Lateral Undulatory Motion

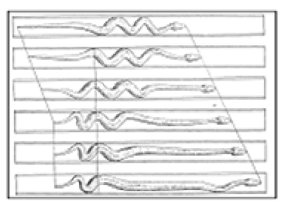

Figure 2. Concertina Motion

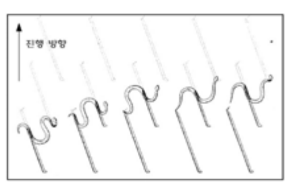

Figure 3. Side-Winding Motion

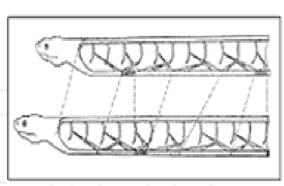

Figure 4. Rectilinear Motion

2.2 System Constitution of Snake Robot

We design a frame of snake robot from biological structure feature of snake. Upper side of figure 5 show us a module that it constitute vertically connection of two servo-motor.
The snake robot consists of 7 modules. And the robot has 12 DOF, because each module has 2 DOF by using 12 linear connecting of servo-motor. A power source is in the tail of robot

for freely activity and Main module is in the head. Length between the head and the tail is 970mm.

Figure 5. Body, Controller and Power of Snake Robot

Snake robot has ultrasonic sensor, CMOS image sensor, gas sensor, temperature, illumination for sensing circumstance. Table 1 means the usage.

Sensor	Use	Character
Ultrasonic Sensor	Distance measurement, Avoidance	Range 3cm~3m
Image Sensor	Color recognition	120X90 Pixel
Gas Sensor	Gas detection	LNG, LPG
Temperature Sensor	Temperature measurement	-55~125 degrees
Illumination Sensor	Illumination measurement	CdS

Table 1. Sensors of Snake Robot

Micro controller in head executes sensor fusion algorism by using sensor input data and this can reason proper action by expert system. Consequence of reasoning is sent to servo motor controller, and then servo motor working.

3. Multiple Sensor Fusion

Robots or systems use sensors to get information from external environment. It is advisable to use several sensors than to use one. It is also advisable to use many kinds of sensor than to use one kind. Like this, using multiple sensors, robots obtain information about their work space and they renew continuously environmental information. Typical examples of using multiple sensors are object recognition, autonomous driving of mobile robot, industrial application, military object, target trace, autonomous driving of flying object.

3.1 Multiple Sensor and Sensor Fusion

The advantages of getting information using multiple sensors are additional redundancy, complementarity, timeliness, and cost of the information. With using several sensors or fusing sensor data, we can obtain many kinds of information that we can't obtain when using only one sensor. Through the obtained additional data in this way, accuracy of information is increased and the importance of element that caused by errors of sensor and data, is decreased. If data of multiple and many kind sensor is processed with parallel, with sensor fusing, than the almost real-time processing is enable, beside using individual sensor.

When comparing data from multiple sensors, information cost of using multiples sensor is lower than single sensor. We must consider modularity, hierarchical structures, adaptability when designing sensor fusion structure. Modular fusion takes effect decreasing system complexity and organizes flexible system without the dependency of specific sensors. If changing sensor the other kind one, there is no need to change whole codes, instead we just change required part.

3.2 Sensor Fusion of Snake Robot

The snake robot has ultrasonic, gas, illumination, temperature and CMOS image sensor. Figure 6 is sensor fusion structure of the snake robot.
Preprocessing of sensor input is included in sensor modeling step. After sensor data is modeled, it is transferred to fusion or separate operation step. There are many kinds of fusion method, generally, neural network is used in lower level and rule based fusion system is used in little upper level. In this paper, complementary neural network is used in ultrasonic sensor fusion. In environment sensor fusion, Radial Basis Function Network (RBFN) is used. And CMOS image sensor, that can affect other sensor processing, is processed individually.

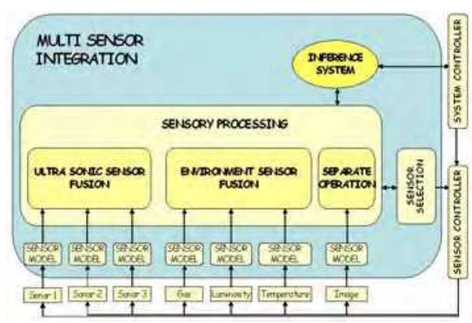

Figure 6. Block Diagram of Sensor Fusion

3.2.1 Fusion of Ultrasonic Sensor

It is profitable to use neural network in low rank department of sensor fusion. This is caused that neural network is having adaptation ability. Because surround environment of robot is variable, it can say that adaptability is indispensable element of sensor fusion. Ultrasonic sensor fusion used competitive neural network(Figure 7).

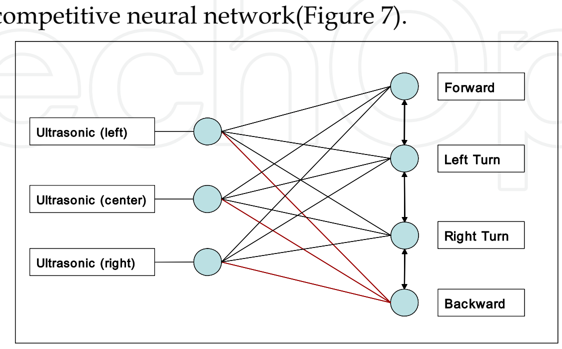

Figure 7. Neural Network using Ultrasonic Sensor Fusion

Fusion module of ultrasonic sensor calculates distance between front side and the right and left sides, and reason traveling path of the snake robot. At this time, Relative difference of each direction-distance is important element, therefore competitive neural network is profitable than general multi-layer neural network. Competitive neural network uses unsupervised learning and classify input pattern without given information about target value. Input values of ultrasonic sensor make regulation. After, that put inner product with weights.

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$$a_j = \sum_{i=1}^{n} x_i w_{ij} \quad , \ (n : input\ munber) \tag{1}$$

Competitive neural network selects neuron that have maximum value of calculated output neuron(Equation 1) and updates weight coupled to the neuron(Equation 2).

$$w_k(t+1) = \frac{w_k(t) + \eta(x(t) - w_k(t))}{\left\| w_k(t) + \eta(x(t) - w_k(t)) \right\|} \tag{2}$$

By using Equation 2, competitive neural network learns until cluster of each learning pair search the center. If we put value of ultrasonic sensor to neural network learned, we can get each output neuron's value and it is used in input of reasoning department.

3.2.2 Fusion of Environment Sensor

The snake robot has gas sensor and temperature sensor to grasp the dangerous degree of surrounding situation. Fusion module of environment sensors estimates dangerous degree of place that robot is situated currently with use value of gas and temperature sensor. Fusion module of environment sensor uses Radial Basis Function Network(RBFN)(Figure 8). We must organize fusion department with use network of simple structure for real time arithmetic. Also, fixing weight between input layer and hidden layer, structure is simple than artificial neural network and show more efficient performance as curtailment of learning time.

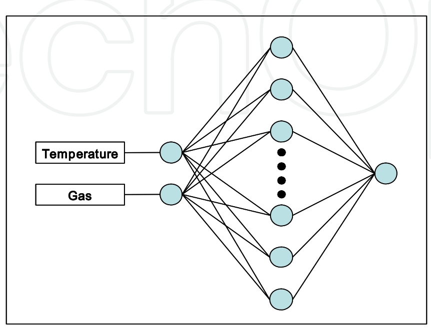


Figure 8. Radial Basis Function Network using Environment Sensors

We used Gaussian function to hidden layer(Equation 3).

$$R_i(x) = \exp\left(\frac{\|x-u_i\|^2}{2\sigma_i^2}\right) \tag{3}$$

3.2.3 Separation Management of Image Sensor

The snake robot can recognizes color and coordinates calculation about target by using CMOS image sensor. Image sensor handles distinction image of 120X90 pixels by YUV format. Equation 4 is formula that YUV format is converted to RGB form.

$$\begin{aligned} R &= (U-128)+Y \\ G &= 0.98Y - 0.53(U-128) - 0.19(V-128) \\ B &= (V-128)+Y \end{aligned} \tag{4}$$

Figure 9 is transmitted information of YUV format by camera and this is changed RGB form. This is confirmed on monitor.

Figure 9. Captured Image using CMOS Camera

Due to limit of a memory, method of image process directly operate image received from camera by pixel instead of frame in a memory. The center and radius of target are calculated by Equation 5 and 6, respectively.

$$Center(x,y) = \left(\frac{(start_x + end_x)}{2}, \frac{(start_y + end_y)}{2}\right) \tag{5}$$

$$radius = \frac{(end_x - start_x + 1) + (end_y - start_y + 1)}{4} \tag{6}$$

If we use this method, memory space and operation speed can increase because image information do not stored in memory.

4. Inference Algorithm of Snake Robot

The snake robot must judge the state of thing automatically and behave. Autonomous judgment of state and process of behavior can solve by soft computing method. For behavior of the snake robot is realized, it demands learning about environment of various kinds and reasoning ability about behavior. Generally, neural network and fuzzy rule base are very useful method for learning and reasoning system. But, the snake robot's main process which consists of 8 bit has weak point that go down calculation ability than the PC's process. So, algorithm for reasoning of the snake robot used possible simple structure's neural networks and recognition and reasoning about various environment used rule base based on knowledge of expert.

4.1 Inference System

Sensor fusion information used input of inference system. Inference system use expert system. Knowledge-based method utilizes rule-based expression method. Rule-based expression consists of next structure.
The snake robot can recognize color and coordinates calculation about target by using

$$\text{IF } \textit{Antecedent} \text{ and } \textit{Antecedent}, \quad \text{then } \textit{Consequent}. \tag{7}$$

Antecedent input of inference system used result which disposed of department of sensor fusion. So Antecedent of fuzzy rule was consisted of direction of ultrasonic sensor, result of environment sensor fusion, illumination value that handled separately and target value. Consequent of fuzzy rule determine movement of the snake robot which consists of 7 actions, and its movement is forward motion, backward motion, left-turn, right-turn, rest, attack and precaution. Each motion appeared from figure 10 to 13.

Figure 10. Attacking Mode

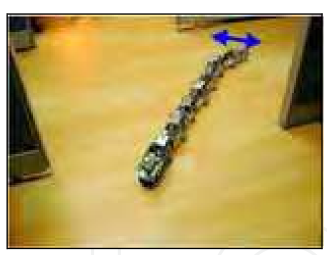


Figure 11. Warning Mode

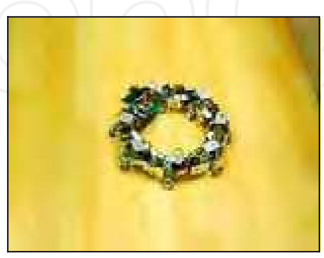


Figure 12. Sleeping Mode

Figure 13. Locomotion Mode

Linguistic variables of direction element are made up of 4 kinds that consist of forward, backward, left and right and environment elements are 2 kinds(Danger, Safe) and target elements are 3 kinds(Nothing, Enemy, Prey). Finally, Linguistic variables of illumination elements is 2 kinds(Bright, Dark). We got 48 rules from all antecedent inputs as figure 14.

Rule 1: If *Dr is F*, *En is D*, *T is E* and *L is B*, then *A is RETREAT.*
Rule 2: If *Dr is F*, *En is D*, *T is N* and *L is B*, then *A is LOCOMOTION*.
Rule 3: If *Dr is F*, *En is S*, *T is N* and *L is Dk*, then *A is SLEEP*.
⋮
Rule 48: If *Dr is Bk*, *E is S*, *T is P* and *L is B*, then *A is ATTACK*.

- *Dr*: Direction, *F*: Forward, *En*: Environment, *T*: Target, *S*: Safe, *D*: Danger, *Bk*: Backward, *L*: Luminorsity, *B*: Bright, *Dk*: Dark, *A*: Action, *B*: Bright, *E*: Enemy, *N*: Nothing, *P*: Prey

Figure 14. Rule Base of snake Robot

5. Experiment

5.1 Computer simulation

We watched movement of the snake robot through computer simulation before real-time experiment of the snake robot hardware. Input for the simulation used distance values(left, front, right) measured by ultrasonic sensor, temperature, gas, illumination and target color measured by CMOS sensor. We easily ascertain fusion result of ultrasonic sensor and environment sensor fusion by computer simulation and get reasoning result of the snake robot using expert system.

Condition of simulation (1) are not target and gas in the surrounding of the snake robot and temperature is 27degrees and illumination is brightness. Also enemy or prey is not appearance. Direction result from fusion module of ultrasonic sensor inferred 'FORWARD' and fusion department of environment sensor inferred that present circumstance is 'SAFETY'. Final inference result obtained form image sensor value is 'LOCOMOTION' by rule 11(Figure 15).

Simulation (2) has the same circumstances identical with simulation (1) but enemy or prey is appearance. Because enemy was superiorly recognized the better than prey, final inference is 'WARNING' by rule 7(Figure 16).

Simulation (3) has the same circumstances identical with simulation (2) and value of gas and temperature are going up. In case, Movement of the snake robot was determined 'RETREAT' because present circumstance from environment sensor fusion inferred danger by rule 11(Figure 17). Simulation (4) is condition that enemy and prey do not appear. And circumstances are 'RATHER SAFETY' condition when gas, temperature and illumination were inferred by rules. Ultrasonic sensor perceives that target is in the left side. So final inference result is 'TURN RIGHT'(Figure 18).

Simulation (5) is a safe condition when gas and temperature was considered. Because prey was appeared, inference system inferred that movement of robot is 'ATTACK' by rule 10(Figure 19).

Figure 15. Computer Simulation (1)

Figure 16. Computer Simulation (2)

Figure 17. Computer Simulation (3)

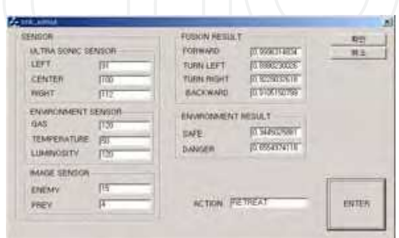


Figure 18. Computer Simulation (4)

Figure 19. Computer Simulation (5)

5.2 Implementing a Real-Time System of Snake Robot

The result of computer simulation showed that the snake robot determined proper judgment in every situation. We implemented the snake robot which consists of several frames to assure that the algorithm operate well in real-time system. We defined the blue object as a prey and the red object as an enemy in the experiment. For example, the snake robot meets across a prey in Figure 20. We defined the blue object as a prey and the red object as an enemy in the experiment. For example, the snake robot meets across a prey in Figure 20. The snake robot estimates the environment whether it is in safety situation or not and then, it attack the prey when it is in safety. Figure21 shows that environment around the snake robot traveling is getting dark. The snake robot takes a break when preys and enemies are not detected by image sensor and gas and temperature sensor display its safety.

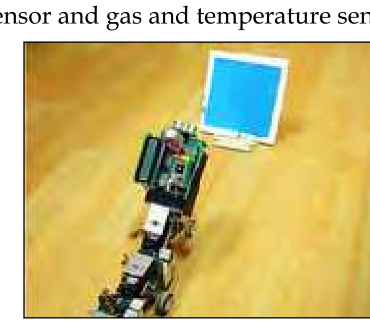


Figure 20. Simulation (1)

Figure 21. Simulation (2)

Figure 22~25 show that the snake robot detected a forward obstacle in traveling. It avoids the obstacle and turns left and goes straight after its the ultrasonic fusion module computes the distance between the snake robot and the obstacle.

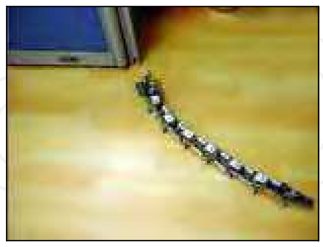


Figure 22. Simulation (3)

Figure 23. Simulation (4)

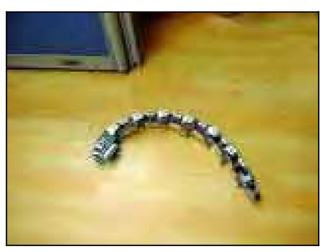


Figure 24. Simulation (5)

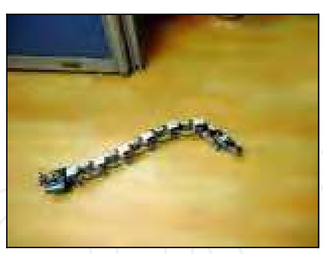


Figure 25. Simulation (6)

6. Conclusion

The goal of this paper in a snake robot and sensor fusion is that the snake robot which imitates a real snake's an activity and being adapted to topography and has multiple sensors operates well with considering environment around it. To avoid overloads of a processor and process a huge data of multiple sensors in distribute methods, fusion module of sensor is constructed in a module. In a low level of sensor processes, we worked sensor fusion processes using neural networks to have adaptability. In a high level of sensor processes, we make the snake robot operate intelligently using expert system in fused sensor data to infer activity of the snake robot. The snake robot is long and elliptical and has sensors on a head. If sensors are located on the snake robot's body and in addition magnetic and voice recognition sensors are used, abilities of the snake robot will be improved. To have the ability of learning in the snake robot, a processor to have a high ability must be used instead of using the processor used to operate the snake robot in this paper.

7. References

Wako Tojima (2001). *Robot kyoshitu*, Kobunsha.

Masashi S., Masakazu F., and Tetsuya I. (2002). Serpentine Locomotion with Robotic Snakes, *IEEE Control System Magazine*. February.

K. Dowling (1999). Limbless locomotion: Learning to crawl with a Snake Robot, *Proceeging of IEEE International Conference Robot Automation*, MI, pp. 3001-3006.

Honda Motor Co. (1996). Honda Biped Robot, News Release. Several news articles including Reuters from December 20.

S. Hirose (1993). Biologically Inspired Robots: Snake-Like Locomotors and Manipulators, Oxford University. Press., New York.

S. Hirose, Morishima, A. (1990). Disign and Control of a Mobile Robotic with an Articulated Body, *International Journal of Robot,* Res, Vol.9, No.2, pp. 99-114.

M. Nilsson (1998). Snake robot free climbing, *IEEE Control System Magazine*, Vol. 18, pp. 21-26.

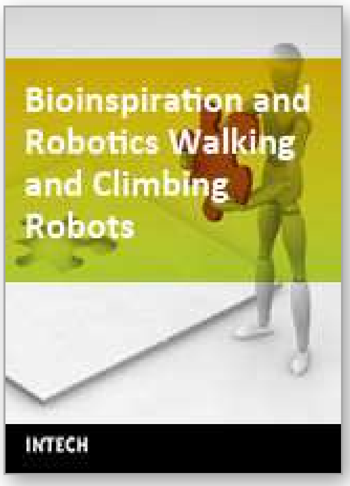
Ren C. Luo (2002). Multisensor Fusion and Integration: Approaches, *IEEE SENSORS JOURNAL*, Vol. 2, No. 2.

J. Gray and H. Lissmann (1950). The Kinemetics of locomotion of the grass-snake, *Journal Exp. Biol.*, Vol. 26, pp. 354-367.

B. C. Jayne (1986). Kinemetics of terrestrial snake locomotion, *Copeia*, Vol. 4, pp. 915-927.

H. Lissmann (1950). Rectilinear locomotion in a snake(Boa occidentalis), *Journal. Exp. Biol.*, Vol. 26, pp. 368-379.

B.C. Jayne (1988). Muscular mechanisms of snake locomotion: An electromyographic study of the sidewinding and concertina modes of Crotalus cerastes, Nerodia fasciata and Elaphe obsoleta, *Journal Exp. Biol.*, Vol. 140, pp. 1-33, 1988.



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