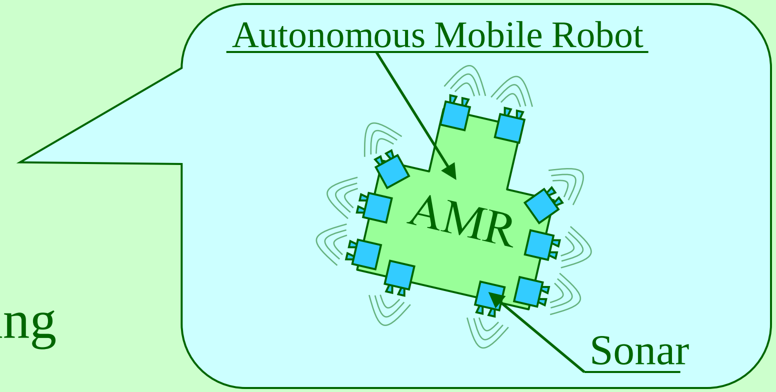
Acquisition of Modulation Pulses for a Multi-Robot System Using Genetic Algorithm

1. Introduction



●Supersonic sonars are usually equipped on AMR for the environment perception.

◇Each sonar measures distance to objects by computing the TOF of the transmitted wave echoed back from a reflecting object and received by the sonar.

◇ For the shorter measurement time, those sonars should be concurrently operated.

◇ Then each sonar transmits a pulse-modulated signal with different pulse pattern.

●When many sonars are concurrently operated, interference among the sonars will be occurred. → **Erroneous measurement** by interference

◇ To completely avoid/reduce such interference, the pulse pattern for the modulation must satisfy some special conditions.

◇ Acquisition of such pulse pattern which completely avoids/reduce signal interference among signals transmitted from different sonars is very difficult.

●We propose a method to acquire such pulse pattern.

●When two or more robots equipped with multiple sonars exist in the same environment, likelihood of performing erroneous measurement is very high.

◇To reduce such difficulty, variation in signal length between all sonars in the same environment should be small.

●Requirements for the pulse pattern (objective functions) are as follows:

★ Length of the pulse pattern should be small,

★ Probability of erroneous measurement (interference) should be small,

★ Variation in signal length between sonars should also be small.

◇This problem is treated as a multi-objective combinatorial optimization problem.

◇This can be solved with the Niched Pareto GA (NPGA).

2.Range Measurement Using Multiple Sonars

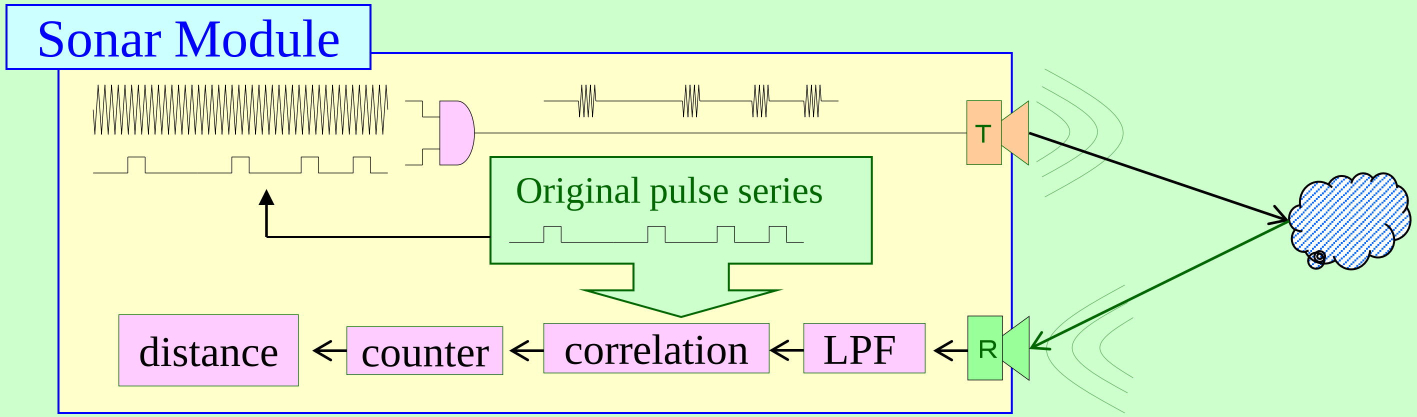


Figure 1: Ultrasonic range sensor (sonar) module.

- The sonar transmits a supersonic wave modulated with an unique pulse series and receives the reflected wave.
- Pulse series is detected from the received wave by the LPF.
- The detected pulse series is compared with the original unique pulse series for each time delay.
- The distance is determined according to the time delay when the received pulse series matches the original pulse series.

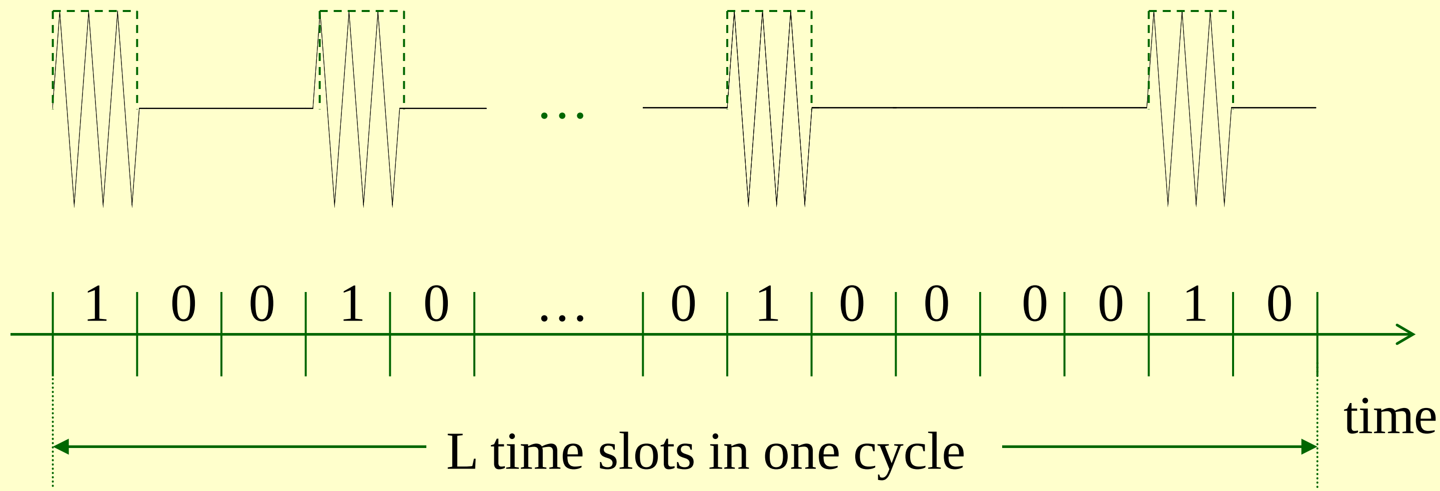
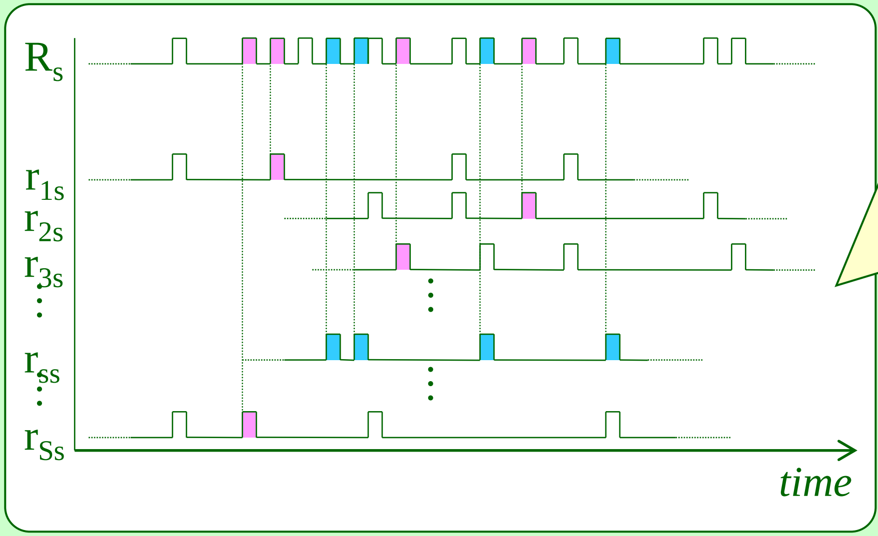


Figure 2: Composition of a pulse series for the pulse modulation.

- The signal is devided by time slot whose length equals the length of one pulse.
- The modulation pulse series is formed by assigning 0 or 1 to the time slots.



- R_s : the received pulse series measured at the sonar s.
- r_{1s} ,…,r_{Ss} : pulse series transmitted from each sonar and received at the sonar *s*. (Espacially, r_{ss} is the original pulse series to be detected.)
- Because all sonars are concurrently operated, R_s is configured by the sum of the pulse series from all sonars.

In this situation, ...

- The received pulse series, R_s, matches the original pulse series, r_{ss} , at several time delays as shown by the red and blue pulse series.
- Although the blue pulse series should be detected, the red pulse series has been detected prior to the blue ones.
- The erroneous pulse series (red pulse series) is accidentally configured by pieces of pulse series transmitted from other sonars.
- This means the interference which yields to the erroneous measurement.

To avoid/reduce such the interference, the pulse pattern for whole sonars must satisfy a condition given by the following expressions.

$$\sum_{i=0}^{L-1} T_A(i) T_A(i+j) \begin{cases} = P & (j = 0) \\ \leq 1 & (0 < j < L) \end{cases}$$

$$\sum_{i=0}^{L-1} T_A(i) T_B(i+j) \leq 1 \quad (0 \leq j < L)$$

- These conditions mean that all interval length between any two pulses are different each other.
- When the pulse pattern satisfies these conditions, a probability of occurrence of the interference (erroneous probability) is minimized.
- Especially when $P>S$, the erroneous probability can be given as zero.
- We call such the pulse pattern a valid pulse pattern.
- However, it is very difficult to acquire such the pulse pattern.

3. Acquisition of Modulation Pulses

- Start with a number table (interval table : g_{sp}) and an array (check list).
- The table contents can be arbitrarily given and represent a set of interval lengths.
- The interval table is transformed to the valid pulse pattern as follows:

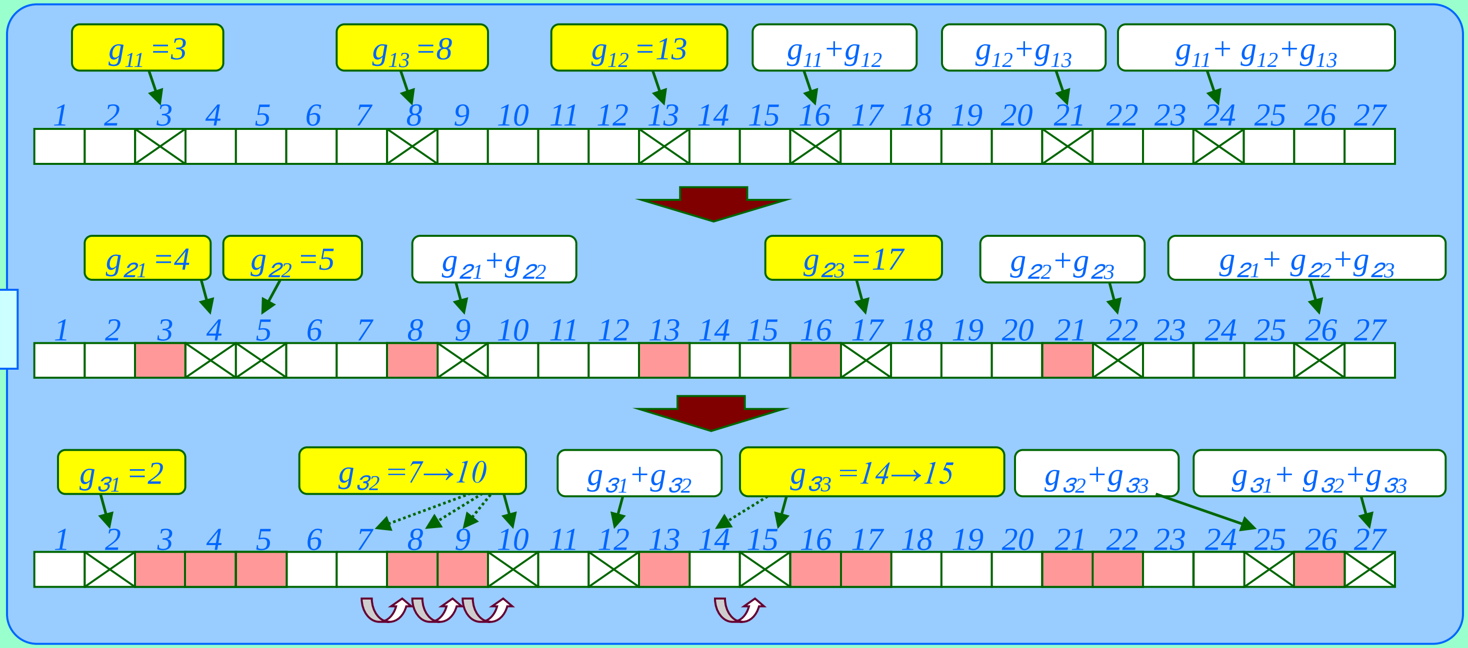
Interval (p)

Sonar (s)	1	2	3
1	3	13	8
2	4	5	17
3	2	7	14

Transformation

Interval (p)

Sonar (s)	1	2	3
1	3	13	8
2	4	5	17
3	2	10	15



(1) Take one element from the interval table.

(2) If all the positions of the check list given by $\sum_{k=0}^{m} g_{s(p-k)}$, for $m = 0,1,\cdots,p-1$ are vacant, cross out those positions and determine g_{sp}.

(3) If one or more those positions are already crossed out, increase g_{sp} by one and repeatedly try to (2).

4. Optimization of the Pulse Pattern by the GA

Generate the initial population using random number.

Transform the individuals and compute their *L*.

Retain elite, giving smallest *L* through the optimization.

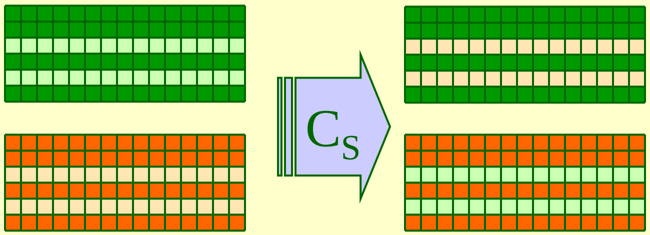
Select two parents at the current generation, one gives smallest *L* except the elite and another one gives smallest deviation of length of pulse series.

Regenerate new population for the next generation from the elite and the parents with genetic operators.

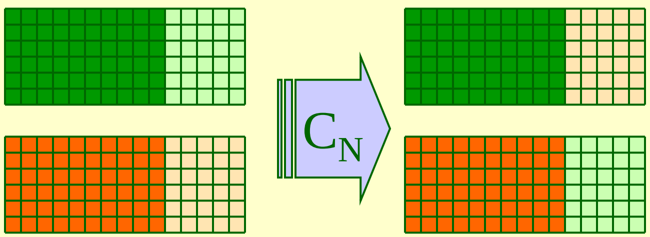
Repeatedly execute for *G* generations.

- Interval table is handled as an individual to be optimized by the GA.

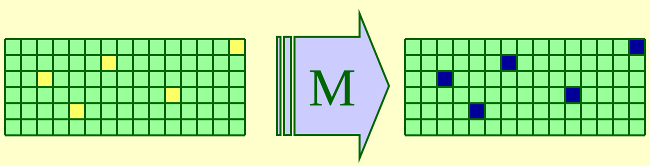
- Genetic Operators



- Crossover operator, C_S, changes some rows selected from two parents each other according to a selection rate, p_{cs} *=0.1*, and creates two new offsprings.



- Crossover operator, C_N, selects a boundary of pulse intervals according to a selection rate, $p_{CN} = 1/(P-1)$, and changes parts divided by the boundary each other.



- Mutation operator, *M*, selects several elements of interval table of a parents according to a mutation rate , $p_M = 0.01$, and randomly changes these elements with width 3

- Population size : 27

4. Optimization of the Pulse Pattern by the GA

- For example, three offsprings are generated from the parent.

parent

	1	2	3
1	3	13	8
2	4	5	17
3	2	7	14

GA operators

	1	2	3
1	3	13	8
2	4	5	17
3	2	[9]	[15]

	1	2	3
1	3	13	8
2	4	5	[16]
3	2	[8]	14

	1	2	3
1	3	13	8
2	4	5	17
3	2	[10]	[13]

The red-colored numbers are modified.

Transformation

	1	2	3
1	3	13	8
2	4	5	17
3	2	10	15

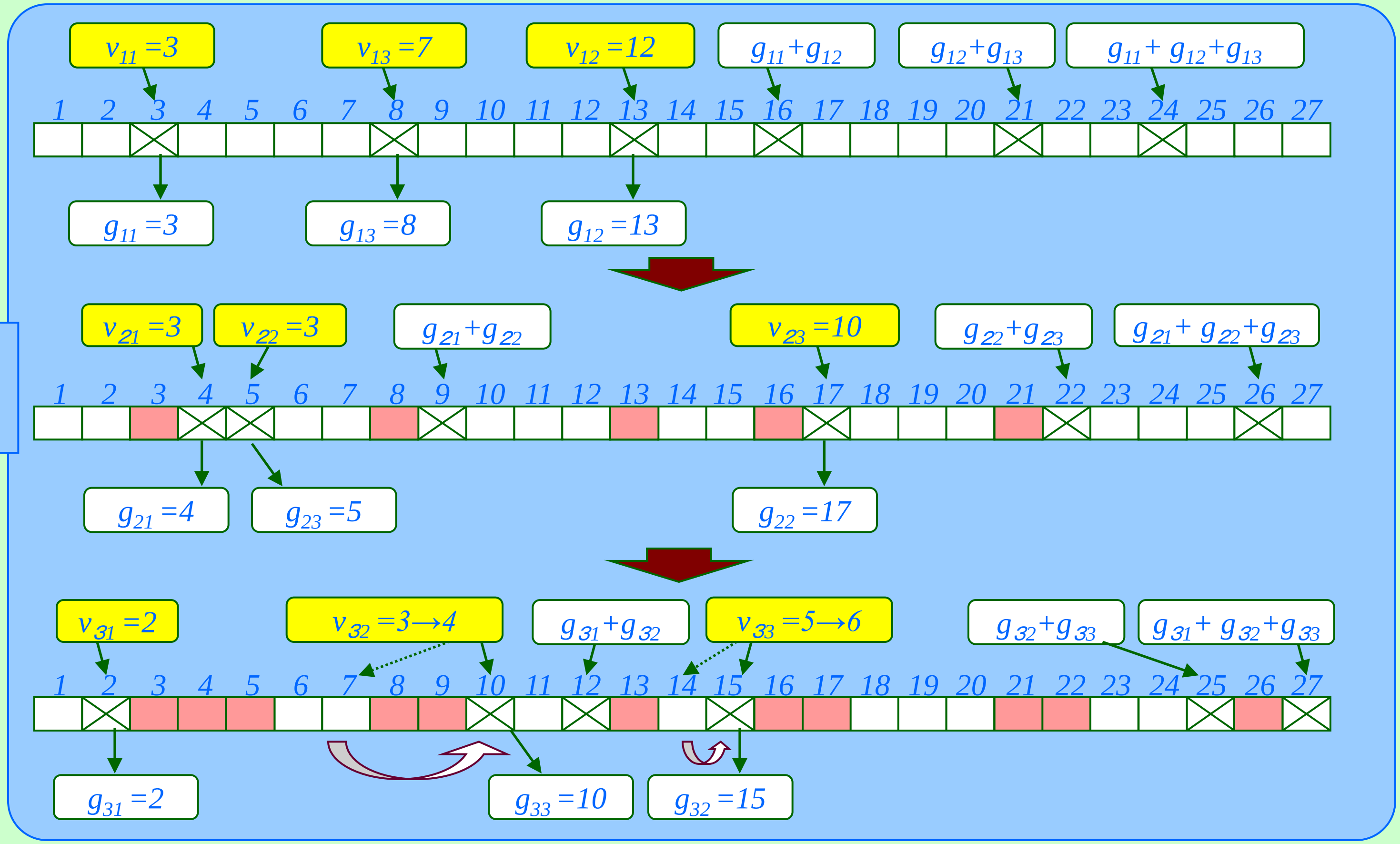
- Those four individuals are transformed to the same pulse pattern and provide the same value of the performance.
- This means that there are futile searches through the GA.
- This is caused by the genotype coding, the interval table is defined as the genotype coding.

● In the improved genotype coding, the genotype code is composed of vacant position numbers of the check list (vacant position table : v_{sp}) instead of pulse intervals.

Sonar (s) \ Interval (p)	1	2	3
1	3	12	7
2	3	3	10
3	2	2	5

Improved Transformation

Sonar (s) \ Interval (p)	1	2	3
1	3	13	8
2	4	5	17
3	2	10	15



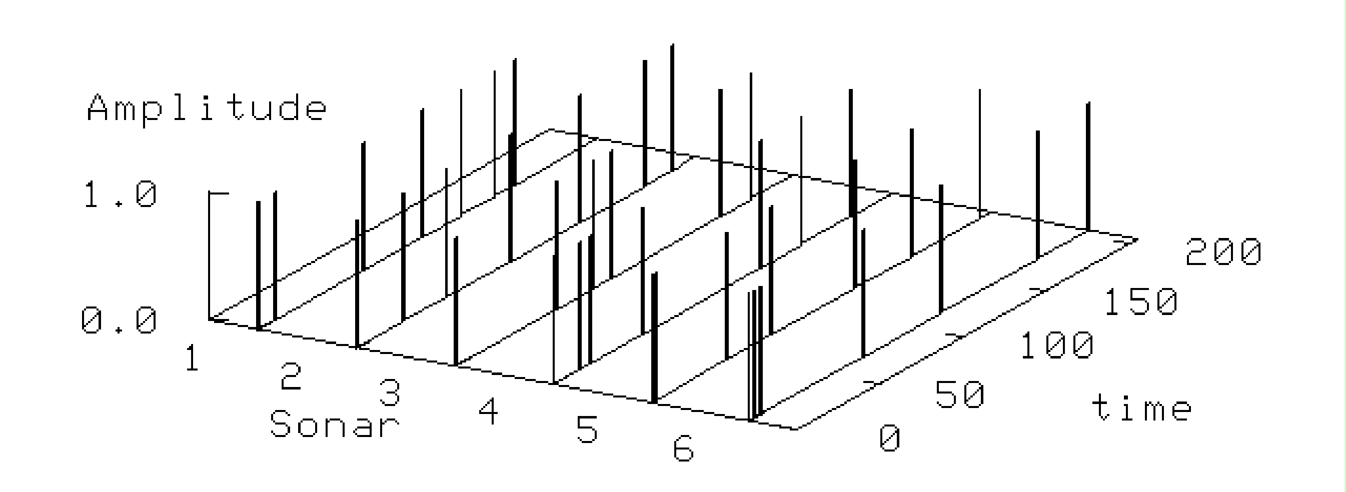
● By means of the improved genotype coding and its transformation, occurrence of such futile search is effectively reduced.

5. Result of the Optimization

● One of results of the interval table for a system with 6 sonars and 7 pulses

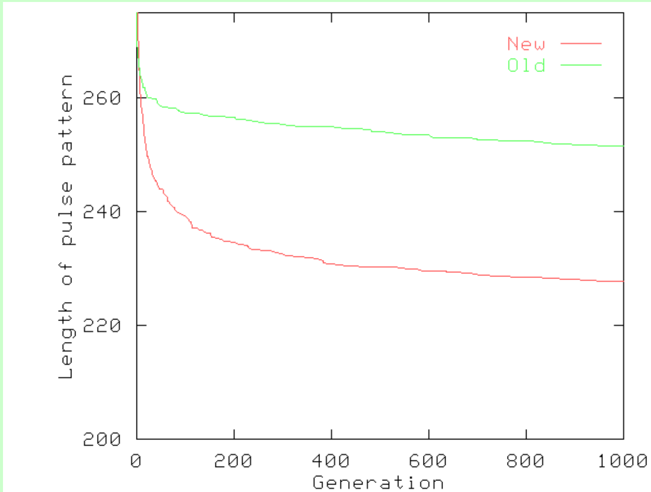
		Pulse interval					
		1	2	3	4	5	6
Sonar	1	10	53	36	23	20	12
	2	28	26	38	42	39	17
	3	1	60	22	11	67	18
	4	16	21	31	72	25	40
	5	2	44	27	50	34	41
	6	3	4	62	47	58	30

● The pulse pattern given by the interval table

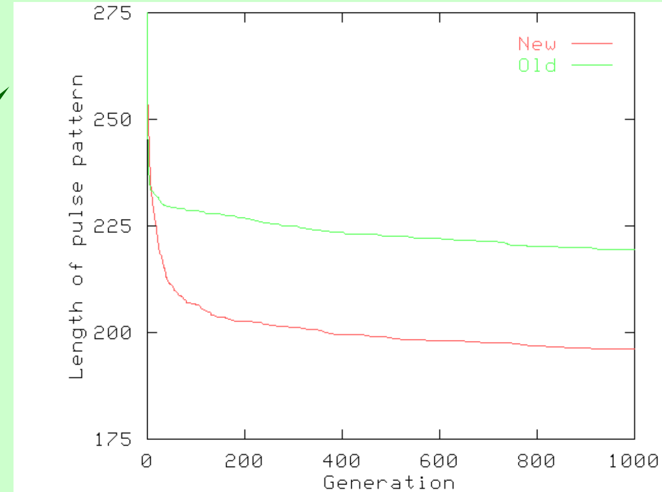


- We executed 30 trials of optimization for several numbers of sonars and pulses.
- Comparison of average length at each generation for 30 trials of optimization

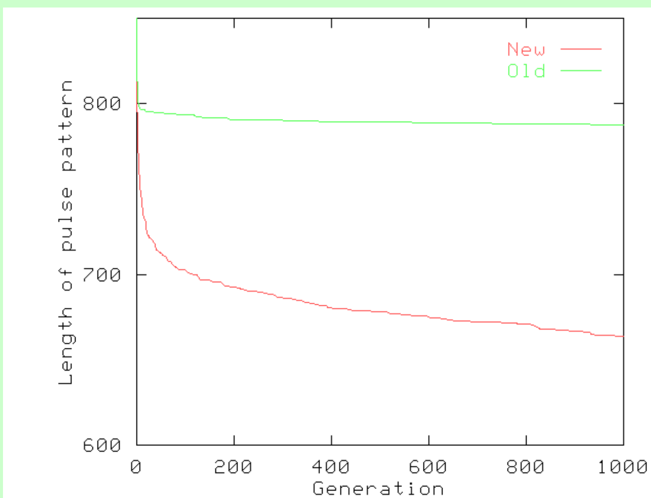
S=6
P=7



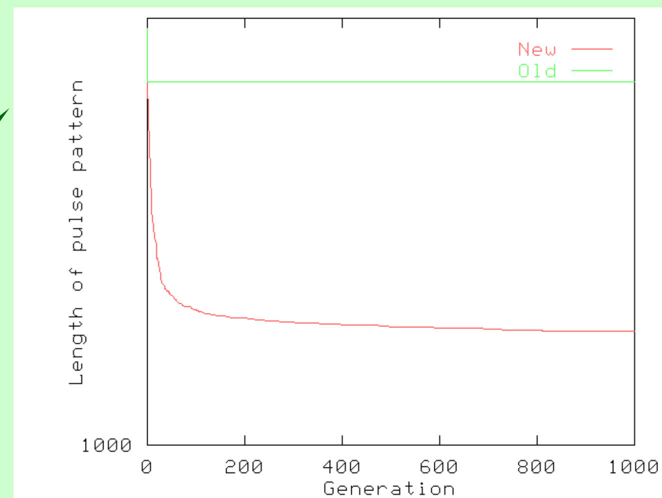
S=8
P=6



S=8
P=9

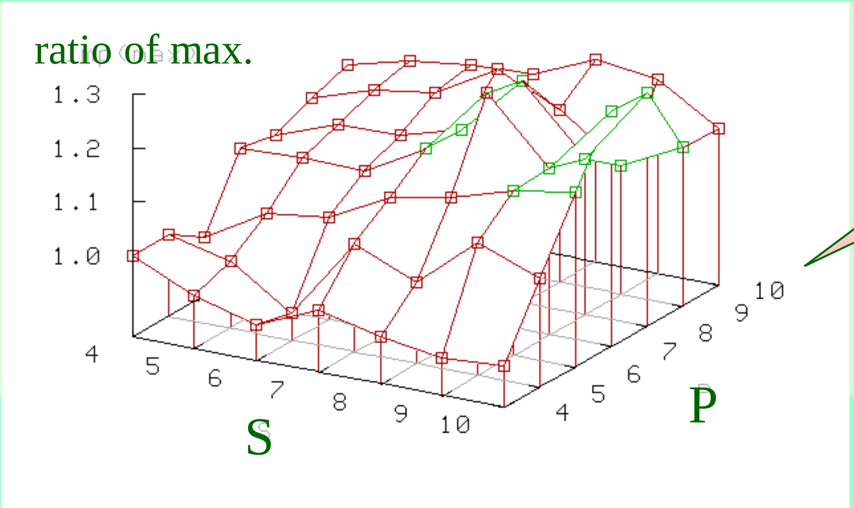


S=10
P=10



- The improved genotype coding with the vacant position table provides better results than the genotype coding with the interval table.

- Ratio of Maximum, average and minimum values given by the primal and improved genotype coding for several numbers of sonars and pulses.
- Larger values of the ration denote the effectiveness of the improved one.

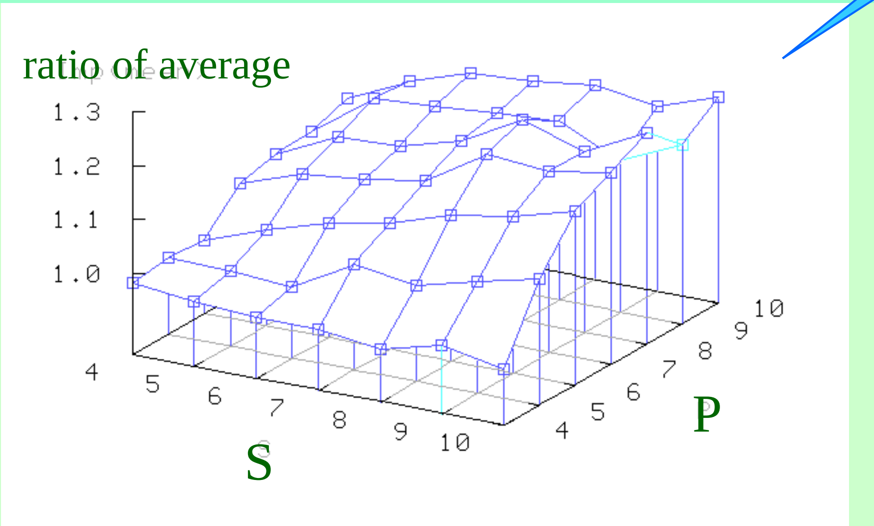


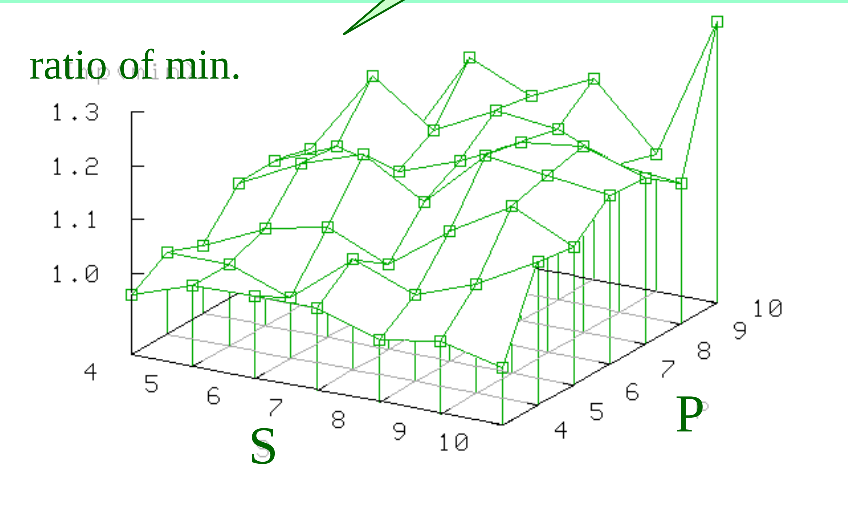
maximum

- The effectiveness of the improved genotype coding are shown in all most cases.

average

minimum





6. Conclusion

- Technique to acquire the pulse pattern for multiple sonars avoiding erroneous measurement and to optimize it so as to have shorter length is proposed.

  Pulse interval length are directly handled as the genotype code.
  (primal genotype coding)

- The primal coding yields futile searches through the GA.
- The genotype coding is improved.

  Vacant position of check list is used in genotype code.
  (improved genotype coding)

- The effectiveness of the improved genotype coding is illustrated.