Optimal Path and Gait Generations Simultaneously of a Six-legged Robot Using a GA-Fuzzy Approach

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1 Introduction

A six-legged robot will have to find a collision-free, time-minimal path and to plan its stable gait in optimal sense (with minimum number of ground-legs having the maximum average kinematic margin) while moving on flat terrain. Three steps are to be considered for legged-robot locomotion - *determination of vehicle's trajectory*, *foothold selection*, and *design of a sequence of leg movements*. In practice, path and gait generations of a legged vehicle are to be done simultaneously. Several attempts had been made by various investigators to solve the problem of combined path and gait generation of a legged robot. In this connection, work of Lee and Song (1991), Chen and Kumar (1996) are worth mentioning.It is important to note that their methods were unable to provide a complete solution to this complicated task. Moreover, the conventional methods are computationally expensive and the generated path and gaits may not be optimal in any sense. Thus, there is still a need for the development of an efficient and computationally faster algorithm.

2 Mathematical Formulation

The hexapod will have to move along a straight path (periodic gait), to take a circular turn (non-periodic gait), to cross a ditch (non-periodic gait) as the situation demands (refer to Fig. 1). The combined form of objective function can be expressed as follows:

$$\text{Maximize} \quad f = \frac{1}{T} + \sum_{i=1}^{NPG} (w_1 \times (6 \times Q_i - C_i) + w_2 \times K_i), \tag{1}$$

subject to the condition that the vehicle is statically stable. where, T is the traveling time, NPG is the total number of non-periodic gait generation mode, Q_i is the number of motion segments in the i-th mode, C_i is the total number of

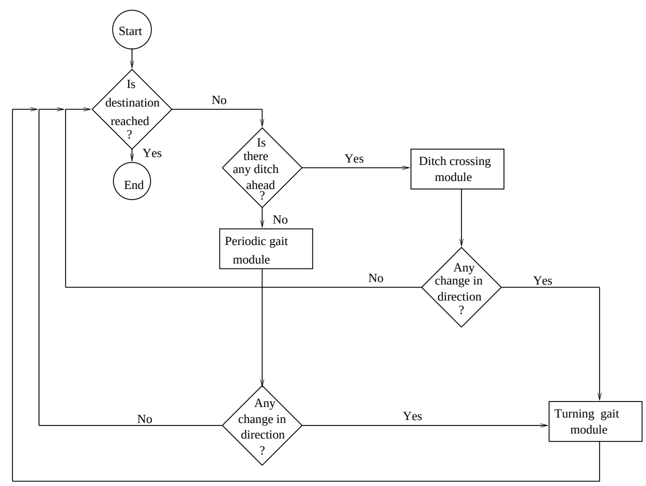

Figure 1 Proposed gait generation algorithm

ground-legs in the i-th mode, K_i indicates the average kinematic margin of the ground-legs in the i-th mode, w_1 and w_2 are the weighting factors.

3 Proposed Algorithm

In the proposed *genetic-fuzzy system*, a genetic algorithm (GA) is used to improve the performance of the fuzzy logic controllers (FLCs) (Thrift 1991). Each leg of the six-legged robot is controlled by a separate FLC and there is one more FLC for determining its path. Thus, there are seven FLCs running in parallel. In the proposed algorithm, optimal path and gaits are generated by FLCs and a binary-coded GA is used to find optimized FLCs. The performance of an FLC depends mainly on its rule base selection and optimizing membership function distribution is a fine tuning process (Pratihar et al. 1999). Two different approaches are studied here. In one approach, the author-defined knowledge base (rule base and membership function distribution) of the FLC has been considered, whereas in the other approach, the rule base of the FLC has been optimized keeping its membership function distribution unaltered. Ten different scenarios are considered during the training phase. It is important to note that optimization (tuning) is done off-line and once the optimized FLCs are obtained, those can be used on-line, for solving the similar problems, in an optimal sense.

4 Results and Discussion

Table 1 Number of ground-legs, C, average kinematic margin of ground-legs, K, traveling distance, D (m) and time, T (sec) obtained by two approaches

	Approach 1				Approach 2			
	C	K	D	T	C	K	D	T
1	336	1.32	37.28	40.28	333	1.34	37.17	40.17
2	548	1.38	42.53	45.53	329	1.32	37.07	40.07
3	340	1.28	37.40	40.40	333	1.34	37.16	40.16
4	551	1.41	42.90	45.90	332	1.34	37.15	40.15
5	550	1.39	42.57	45.57	333	1.35	37.20	40.20
6	-	-	-	-	331	1.32	37.12	40.12

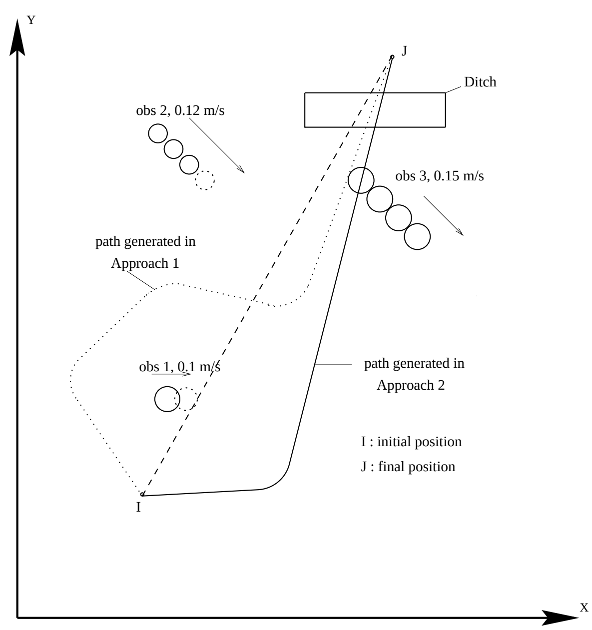

Figure 2 Generated paths in Approaches 1,2

Table 1 presents the results of the two approaches. In this table, three scenarios (out of 10) used during the optimization process are shown in the first three rows. The subsequent three rows show three different and new scenarios. In scenario 6 (Table 1), the author-defined FLCs have failed to generate stable gaits, whereas the GA-tuned FLCs have successfully done it. In all cases, the GA-tuned FLCs are found to perform better than the author-defined FLCs. It happens because the author-defined knowledge base may not be optimal in any sense. Fig. 2 shows the path traced by the CG of the vehicle in two approaches for scenario 4 (Table 1). It is observed that Approach 2 finds a better path (in terms of traveling time) compared to Approach 1.

5 Conclusions

From this study, following conclusions can be made:

1. The proposed algorithm is able to solve the problem of combined path and gait generation of a hexapod effectively.

2. As optimization (tuning) is done off-line, the proposed algorithm is suitable for solving the similar problems on-line, in an optimal sense. As an FLC is less expensive computationally, the proposed algorithm will be computationally quicker (execution time is found to be 1.0 sec in a HP9000/K200 machine) compared to the traditional methods of gait generation.

3. The rule-base optimization involves the problem of dealing with discrete variables and GA is a powerful tool for this purpose.

In future, the similar problem will be solved using the FLCs designed by a GA automatically.

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