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Parameter optimization of a four-legged robot to improve motion trajectory accuracy using signal-to-noise ratio theory

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ABSTRACT

When a multi-legged robot moves, the accuracy of robot movement can be affected by many mutually dependent noise factors such as errors during manufacture and assembly, the joint gap, and the deflection of links. In this paper, we present a parameter optimization method to improve motion trajectory accuracy. One important research objective is to discover parameter values which can be selected to make robot movements more accurate without having to improve the noise generating factors. Our method combines signal-to-noise ratio (SNR) theory with Taguchi technology. We use a four-legged robot-MiniQuad following a beeline tread as an example. Our proposed procedure consists of three stages. Stage 1: SNR theory is introduced to evaluate the impact of parameter change on the robot pose, by using the fluctuations in the robot's pose as the signal, and parameter fluctuations as the noise. Stage 2: A motion model for the robot's fluctuating pose was built. Stage 3: The maximization of "SNR" is used as an optimization object that is based on determining the parameters significance. Taguchi technology is used to realize the robot parameter optimization. For a group of optimized parameters, the body's trajectory fluctuation is minimized when the robot has the same amount of noise factors. Our experimental results of the four-legged robot show that our approach is useful and will aid further improvements for optimizing and designing parameters of multi-legged robots.

1. Introduction

Because legged robots can be used for a wide range of applications, they have attracted the attention of researchers worldwide [1,2]. One research objective is to improve the trajectory accuracy of a multi-legged robot. However, the geometric parameters of the robot (including the structure parameters and input variables) are often not very accurate. These inaccuracies are due to errors during manufacturing, assembly, or the control systems, and other factors. Thus for a given motion target, when a robot moves according the control model formed using the theory parameters, these errors will cause the robots true pose to differ from the desired pose. In fact, to improve the trajectory accuracy is to precisely make legged robot critical stable when using zero moment point (ZMP) method and avoid model errors, which often incurs motion bias.

Many researchers have developed error models to investigate how the robot parameters affect the robot pose. Typical methods include the matrix method [3], the mechanism motion velocity analysis method [4], and the differential equation method [5]. For example, Lichter et al. [6] studied the motion errors of a binary robot. Cui et al. [7] used error modeling for a TAU robot, and Chebbi et al. [8] studied the pose errors of a 3-UPU parallel robot. The authors of this paper, Wang et al. [9,10], have previously discussed the error analysis of a multi-legged robot using the differential equation method.

The purpose of this paper is to find the optimal parameters that enable the robot to move with higher accuracy with same parameter errors.

Dimensional synthesis and parameter optimization were used by many researchers as a means to improve robot performance [11–14]. For example, Seriani used an index to evaluate the efficiency of the workspace of a 2-link CDPR [15]. Yong et al. designed and optimized a novel six-axis force/torque sensor, for a space robot [16]. Surbhi et al. optimized the design of a 3 DOF serial robotic arm to find multiple adjacent possible locations of openings/holes [17].

To the best of our knowledge, however, nobody considered the motion trajectory accuracy by optimizing the structural parameters based on the error model, for a multi-legged robot.

Optimization design of general manipulator has used various metaheuristics such as a genetic algorithm [18], simulated annealing [19], and non-linear search optimization [20]. Investigating the motion trajectory accuracy by optimizing the structural parameters require the use of statistics, the Taguchi method was employed to optimize robot parameters.

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The Taguchi method was originally proposed by Genichi Taguchi [21] and has been widely used for robot design. Wu et al. [22] applied the Taguchi method to determine a robot's accuracy and repeatability for different operational factor settings. Rout et al. [23] applied the Taguchi method to find the optimal setting of parameters to increase the positional accuracy of a manipulator. Bhalamurugan et al. investigated the performance characteristics for an industrial robot, ABB-IRB1410, using the Taguchi orthogonal array [24]. The Taguchi method has been rarely used to study multi-legged robots.

To optimize the parameters that provide the robot with higher kinematic accuracy with same the parameter errors, we use SNR analysis. It is also used to design the optimal parameters by maximizing the SNR.

More specifically, we select the structural parameters for the robot, while considering structure layout, movement performance, and gait requirements. These parameters are allowed to change within the given range to yield different level-values for each structural parameter. For every level-value, several level-motion errors are given, which represent noise that affects the movement accuracy of a multi-legged robot. Furthermore, we determine (experimentally) the factors that significantly affect the robot's pose, and an orthogonal array is applied to simplify the experimental design process.

To identify the parameters with the maximum impact on the robot's pose fluctuation, the factors that affect the motion error of the robot are regarded as noise, and the robot's pose fluctuation is used as the output signal, a SNR analysis is used. The Taguchi method is used to evaluate the effect of the parameter change on the robot's pose.

After identification of the parameters that have a maximum impact on the robot's pose variations, suitable parameters, and parameter combinations, were chosen to reduce the fluctuation of the body's pose for the robot with a given gait. These parameter values are obtained through a comprehensive evaluating of the data for each gait. These parameter values are regarded as "optimized parameters".

After experimental testing of the robot, the robot with the selected parameters was more accurate with regard to its gait, while it has the same associated noise. This confirms that the selected parameters represent optimized parameters. This paper presents a detailed algorithm for the optimization of the parameters for a multi-legged robot moving with a given gait. For different gaits, the optimization parameters may be different, but the optimization process of the robot's parameters follows the same principles.

The two new approaches used in this paper are:(1) By introducing SNR analysis and using the factors that affect the motion trajectory error of the robot as noise, and using the accuracy of the robot's pose fluctuation as output signal, the object function, SNR, serves to optimize the parameter values for the robot. This enables higher accuracy of movement, even though the robot has the same "noise". (2) The Taguchi method is used to design the parameters of the robot by maximizing the SNR.

The remaining paper is organized as follows: Section 2 is a detailed description of basic process of parameter optimization for a four-legged robot. Section 3 discusses the motion error fluctuation model. An example of parameter optimization is provided in Section 4. An experimental test is described in Section 5, and the conclusions are summarized in Section 6.

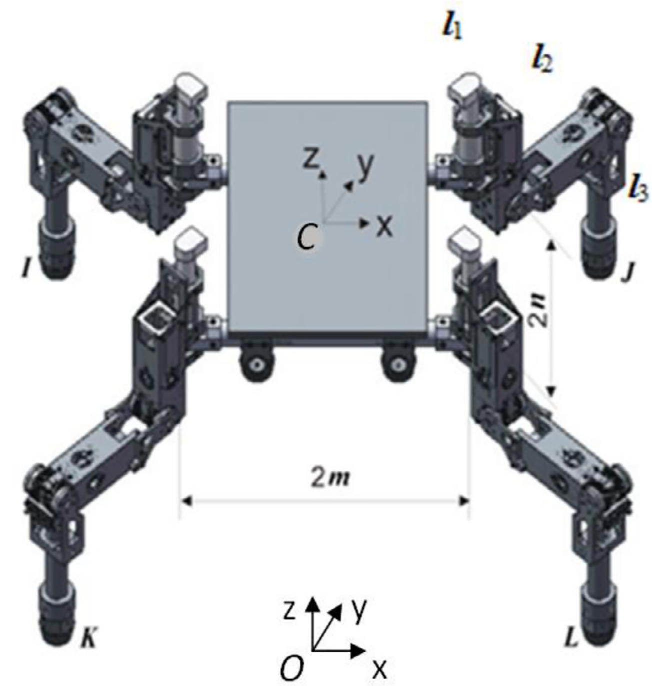

Fig. 1. Three-dimensional structure of robot MiniQuad-I.

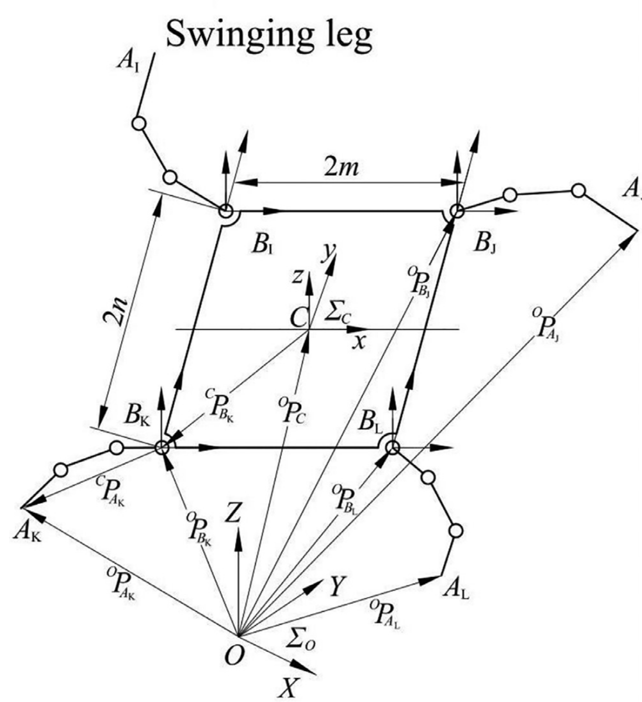

Fig. 2. Schematic drawing of quadruped robot when creeping.

2. The basic process of parameters optimization of a four-legged robot based Taguchi method

2.1. The structure model of robot MiniQuad-I

In this paper, a reptile-like quadruped robot is studied. The robot consists of a rectangular body and four legs. In the process of movement, three legs act as supporting legs, and one leg acts swinging leg. Fig. 1 is a three-dimensional model of robot MiniQuad-I developed at the Huazhong University of Science and Technology (HUST). Fig. 2 is a schematic of the robot describing leg I as the swing leg.Σ_O is the global reference frame set on ground,Σ_C is the coordinate frame attached to the robot's body. Its base point coincides with the geometric center of the robot body. The size of the rectangular body is $2m \times 2n$, $2m$ is the length, and $2n$ is the width. The lengths of the links are l_1, l_2, l_3. There are 6 DOFs for the robot body, and nine driven joints in the three supporting legs.

Fig. 3 shows the projection of the robot in the $x - y$ plane of Σ_c. Fig. 4 is the schematic drawing of a supporting leg with three driven joints and six DOF. Here, l_1, l_2, l_3, ϕ_i, χ_i and φ_i represent structure parameters and joint variables, respectively, L_i and H_i denote the stretch of the