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Fault-tolerant crab gaits and turning gaits for a hexapod robot

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SUMMARY
This paper studies crab gaits and turning gaits of a hexapod robot with a locked joint failure. Due to the reduced workspace of a failed leg, fault-tolerant gaits have limitations in their mobility. Based on the principles of fault-tolerant gait planning, periodic crab gaits and turning gaits are proposed in which a hexapod robot carries out tripod walking after a locked joint failure, having a reasonable stride length and stability margin.

KEYWORDS: Hexapod walking robot; Gait study; Locked joint failure; Crab gaits; Turning gaits.

I. INTRODUCTION

A fault-tolerant gait of multi-legged systems is defined as a gait which can maintain the gait stability and continue its walking against the occurrence of a leg failure. The principle of fault-tolerant gait planning for a locked joint failure[1] is that when the failed leg is in the support phase, the robot body stands still and when the failed leg is in the transfer phase, it does not have an active swing and is moved only passively by the translation of the body.[2] The objective of this paper is to develop fault tolerance against a locked joint failure with non-straight line locomotion: crab gaits and turning gaits. In particular, fault-tolerant periodic gaits are proposed for a hexapod robot to have post-failure tripod walking over an even terrain with crab gaits and turning gaits, respectively. A hexapod robot with symmetric structure is used as the model of legged systems and an attached leg is composed of two rigid links and three revolute joints, having a rectangular working area.

II. FAULT-TOLERANT GAITS

Based on the aforementioned principle, the fault-tolerant periodic crab gait is proposed first. Figure 1 shows the proposed tripod crab gait where a locked joint failure occurs to leg 1. R_α is the length of the foot trajectory with the crab angle $\alpha(0 < \alpha \leq 90°)$. Because the failed leg does not have active swing, the stride length λ cannot be greater than R_α[2] and lies in the range of $0 < \lambda \leq R_\alpha$. According to the leg sequence of the standard tripod gait, the tripod (2, 3, 6) is lifted off first in Figure 1(b) and moved as much as λ, while the robot body stands still. Then, another tripod (1, 4, 5) including leg 1, the failed leg, is lifted off and moved passively with the translation of the body by λ in Figure 1(c), which completes one cycle of the gait. If there is no time lag between the states of Figure 1(a) ∼ (c), the duty factor of the proposed crab gait is found to be 1/2, the same as that of the gait with straight-line motion.[2] This implies that the hexapod robot maintains its mobility as much as the straight-line motion against a locked failure even though it walks with a non-zero crab angle. Also, note that the gait stability of the crab gait, determined as the shortest of S_{145} (Figure 1(b)) and S_{236} (Figure 1(c)), is always a positive value if $\alpha > 0$. This means that the fault-tolerant crab gait is advantageous over the straight-line motion in terms of the gait stability.

Among various types of turning gaits, spinning gaits, in which the turning center is at or closed to the center of gravity, are concerned in this paper. For the simplicity of analysis, we assume that the turning center is coincident with the center of gravity. Figure 2 is an example of the fault-tolerant periodic tripod spinning gait where a locked joint failure occurs to the main actuator of leg 1 with the locked angle at $\hat{\theta}_1(<0)$. The spinning gait is supposed to have counterclockwise turning and the circle with the maximum radius $r_{\max}$ as the foot trajectory. As the tripod (1, 4 ,5) does not participate in the backward movement for the translation of the robot body, it is most desirable to select the foothold positions such that the tripod has the maximum stability margin. Thus, in the initial state in Figure 2(a), leg 5 is placed on the mirror point of leg 1 with respect to the bisecting line of leg 3's working area and leg 4 is placed onto the bisecting line, making the support pattern an isosceles triangle. According to the scheme for spinning gaits presented in the literature,[3] the maximum turning angle for each tripod is given by

$$\Phi_{145} = \min(\Phi_{1\max}, \Phi_{4\max}, \Phi_{5\max})$$
$$\Phi_{236} = \min(\Phi_{2\max}, \Phi_{3\max}, \Phi_{6\max})$$

where $\Phi_{i\max}$ is each leg's maximum turning angle. Since the tripod (1, 4, 5) is moved passively, Φ_{236} decides the maximum turning angle of the gait. We can observe from Figure 2(a) that $\Phi_{2\max} = \Phi_{6\max} = \Phi_2$, $\Phi_{3\max} = \Phi_{4\max} = \Phi_4$ and $\Phi_2 < \Phi_4$. Hence Φ_2 is finally chosen as the angular stroke of the spinning gait and in the initial state, legs 2, 3 and 6 are placed Φ_2 behind their front boundaries on the foot trajectory. Figure 2(b) shows the state of the spinning gait after the completion of one cycle. A white circle denotes the previous location of the foothold position of each leg. Note that the robot body has rotated by the angular stoke Φ_2 and the angle of main actuator of leg 1 has been locked at the same value with respect to the robot body throughout the rotation.

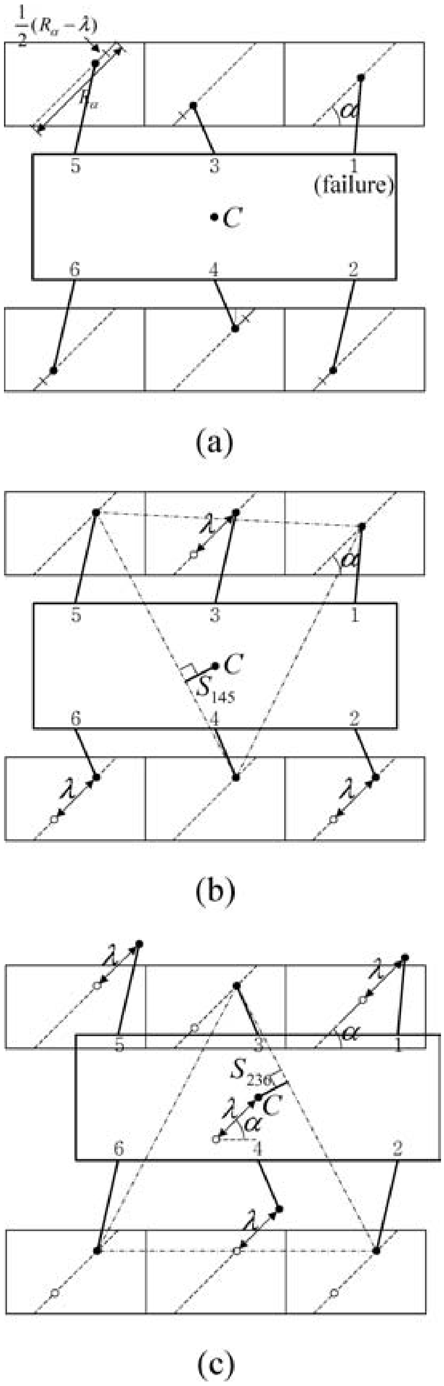

Fig. 1. Fault-tolerant periodic crab gait: (a) initial state, (b) swing legs 2, 3 and 6 and (c) swing legs 1, 4 and 5 with body moving.

Applying the proposed scheme used in the gait of Figure 2, we will easily derive other periodic spinning gaits with a different radius and position of the locked joint.

III. CONCLUSION

Fault-tolerant crab gaits and turning gaits against a locked joint failure have been developed in this paper. Both gaits

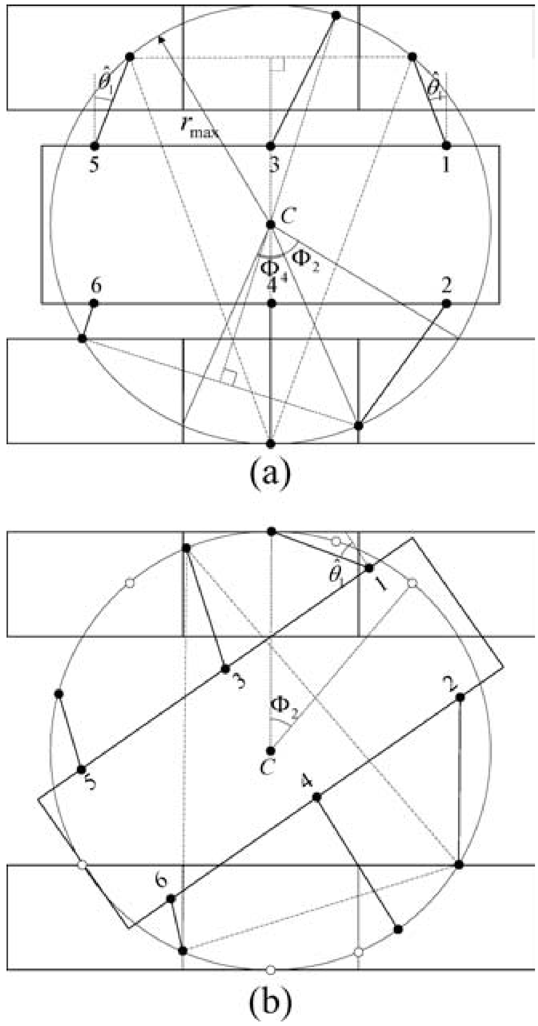

Fig. 2. Periodic tripod spinning gait for a locked failure at joint one of leg 1: (a) initial state and (b) completion of one cycle.

have been generated by the same principle that the failed leg with a locked joint is used only in the support operation and is excluded in the forward transfer of the robot body. As a special form of the proposed gaits, periodic tripod gaits have been proposed for both crab and spinning walking, and their leg sequences and the stride length were analytically driven.

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