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Experimental Verification of the Walking and Turning Gaits for A Two-Actuated Spoke Wheel Robot

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Abstract—**Intelligent Mobility Platform with Active Spoke System (IMPASS) is a novel wheel-leg hybrid robot that can walk in unstructured environments by stretching in or out three independently actuated spokes of each wheel. This form of novel locomotion has the potential to combine the efficiency of a wheeled robot and the mobility of a legged robot. A highly mobile robot such as IMPASS could prove very valuable in applications where the terrain is complex and dangerous, such as search and rescue, reconnaissance, or anti-terror response. This video presents the experiments and findings of a variety of straight-line walking, transitions, and turning gaits. With the 1-1 and 2-2 straight walking gaits, the robot can move forward stably but with different constraints. Unlike other wheeled vehicles which use Arckerman steering or differential steering, IMPASS can implement novel turning gaits even though the left and right hubs rotate with the same angular velocity. Steady state turning gait is demonstrated with skew transitions. Additionally, a free form gait is demonstrated using joystick control with interesting observations.**

I. INTRODUCTION

Recently, leg-wheel hybrid robots have been drawing more attention since they have the advantages of both legs and wheels. Legged locomotion is more adaptable to a wide range of unstructured grounds, but the complicated mechanism of the legs is very difficult to implement. On the other hand, wheeled locomotion is fast and efficient, but it tends to be limited to relatively smooth terrain. Therefore, in order to create a walking machine that combines the benefits of both locomotion schemes, the combination of legs with wheels creates a more effective candidate. Previous researchers considered designing a robot that has both wheels and legs, such as RHex [1] and Whegs [2]. Recently, the Robotics and Mechanisms Laboratory (RoMeLa) at Virginia Tech utilized the concept of actuated spokes and proposed a novel hybrid locomotion platform IMPASS, Intelligent Mobility Platform with Active Spoke System, as shown in Figure 1, which incorporates the benefits of wheeled, legged, and spoke systems. The prototype demonstrated in Figure 1 has two spoke wheels and one tail. It is designed to walk on various terrains, cross over obstacles, and climb up steps using its unique ability to intelligently extend and retract its spokes. System design, kinematic modeling, and preliminary analysis on motion profiles, walking, and turning states have been investigated in previous works [3-8].

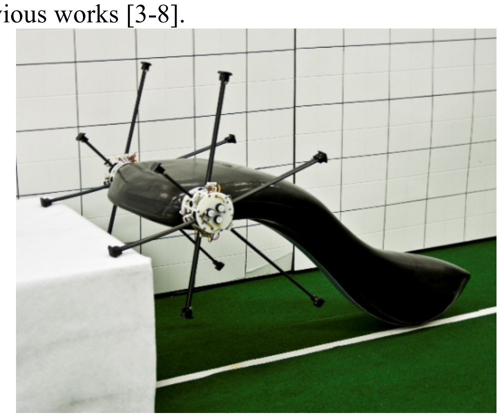

Fig. 1. IMPASS Prototype

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II. EXPERIMENTAL VERIFICATION OF STRAIGHT-LINE WALKING AND TURNING

A. *"1-1" Straight walking gait*

In "1-1" straight walking gait, only one spoke touches the ground for each left and right actuated spoke wheel. The standard "1-1" straight walking gait, shown in Figure 2, has been implemented with the prototype for all previous work, and currently is the preferred gait for most movement. It has proven to be a stable and capable walking gait, including being able to walk over moderately rough terrain without any active adaptation. With no slip assumption at the contact point, this provides two degrees of freedom, so the trajectory of the body can be shaped in sagittal plane. In the video, the body traces a straight horizontal line

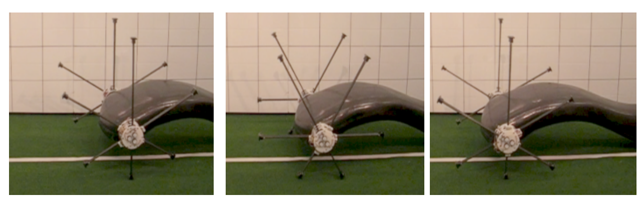

Fig.2. "1-1" Straight-line walking

B. *"2-2" Straight-line walking gait*

In "2-2" straight walking gait, two spokes touch the ground for each left and right actuated spoke wheel. The "2-2" straight walking gait has been verified on the robot as seen in Figure 3. This gait is more stable than the "1-1" walking gait, because it has 5 contact points (including the tail) with the ground, where the "1-1" walking gait only has 3. This creates a closed loop mechanisms where the center of the hub needs to follow a circular arc trajectory in order for the foot not to slip.

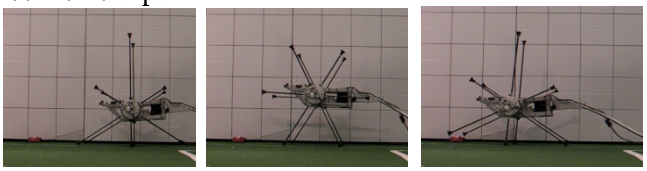

Fig.3. "2-2" Straight-line walking

C. Steady state turning

Unlike other wheeled vehicles which use Arckerman steering or differential steering, IMPASS can implement novel turning gaits even though the left and right hubs rotate with the same angular velocity. A constant radius turn for IMPASS is accomplished using the "1-1, parallel, unequal" walking gait with the mode of "2-2, parallel, unequal" as the transition. This gait sets a smaller effective wheel radius for the inside hub, and a larger effective radius for the outside hub, as shown in Figure 4.

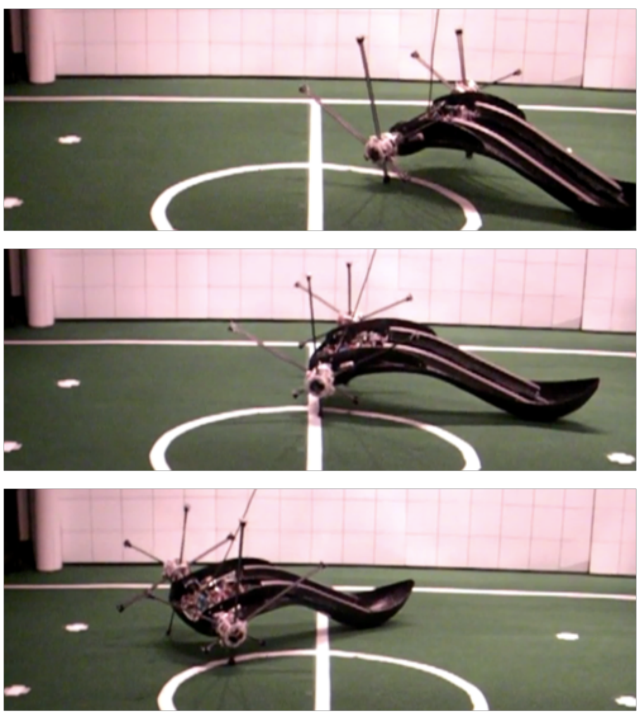

Fig.4. Steady state turning

D. Turning gait transition and "1-1 skew" mode

The turning gait transition is used to switch between straight-line walking and a steady state turn, or between two different radii steady state turns. As shown in Figure 5, the transition from straight-line walking to a steady state turn was demonstrated on the prototype.

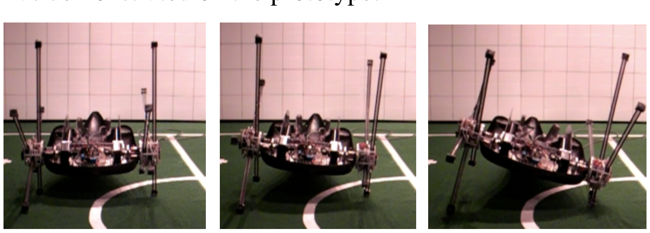

Fig.5 Turning Gait Transition

The turning gait transition takes advantage of the "1-1 skew" mode of IMPASS. While there is slight flex in the spokes during this motion, the prototype of IMPASS remains stable and controllable over this range of motion.

E. Joystick control and interesting observations

Besides forward and backward moving, the height, roll, pitch, yaw of IMPASS can be controlled through the use of a joystick connected to the laptop. This joystick allows simple commands to be input into the IMPASS software. The deviation from the rigid kinematic model to physical prototype is the result of multiple factors, including the offset of the spokes in the hub, and compliance of the spokes.

III. Conclusion

The walking and turning gait experiments of the spoke wheel robot are presented in this video with the emphasis on its straight-line walking with "1-1" gaits and "2-2" gaits, steady state turning, and turning gait transition. The results show that this spoke wheel robot is able to perform well on the ground with potential for effective unstructured environmental mobility. The support of the National Science Foundation under Grant No. 0535012 is gratefully acknowledged.

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