Tendon Inspired Leg Design

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***Abstract*—In this paper, we aim to design a bio-inspired leg which reduces the stress and strain incurred in the process of locomotion. Considering MIT Cheetah's leg as the base design, we propose the first modification as a tendon inspired support at the rear of the lower leg. The second modification is going to be leg dimension modifications based on canine morphology. We show that both these modifications reduce the induced stresses on the bones and present a novel leg design for optimal locomotion.**

***Index Terms*—quadruped robots, bio-inspired robotics, leg design, leg morphology**

I. Introduction

Quadrupedal locomotion has been a common means of travel in robots and constantly improving over the years. Although wheeled locomotion is faster, legged locomotion is more adaptable and maneuverable in rough terrains found in nature [1]. Among legged locomotion, quadrupedal locomotion is highly valued for its versatility as it has higher stability and can handle greater loads than bipedal robots, and less computational and manufacturing complexity than multi legged robots [2]. Quadrupedal robots commonly employ 3 gaits: walking, trotting, and galloping; however, galloping is seldom used due to increased complexity and thus walking and trotting (and the transitions between) are the most implemented gaits [3]. For these reasons we decided to focus on a leg design meant for a quadruped robot and best suited for trotting. This would be most beneficial to most general use mobile robots.

A. Inspiration

Bio-inspired leg design from the amount of articulation in the leg to the structure of the sub-appendage members has been shown to have a better load rating and bear higher stresses than simple prismatic leg design [2]. MIT took bio-inspired design one step further in 2012 when they added tendons to the MIT Robotic Cheetah [4]. They found that the additional tensegrity greatly reduced bending stresses in the leg and would improve energy efficiency during a stride by storing energy in the tendon and releasing it at the end of the stride. By replicating the Achilles tendon they were able to reduce bending stresses in the leg by as much as 67% when pressure was applied to the ball of the foot. These results clearly show the advantage of the tendon–bone co-location design in providing for reinforcement on the leg and thus enabling design of high strength to weight ratio structures.

However, the Cheetah leg was designed for speed and was tested with a galloping gait. We believed the leg could be improved for a trotting gait. Cheetahs are well known for the speed of their gallop, but not as much for their trot. Dogs are known to have multiple gaits and commonly trot. Since canines are much more efficient at trotting as compared to cheetahs [5], we propose that a quadrupedal robot integrated with the anatomies of a canine would be much efficient in sustaining stress at the same weight. We decided to base our leg design on canine morphology. Additionally the tendon will be modified to be an actuator as well.

II. Experiment and Methods

A quadrupedal robot leg was modelled on SolidWorks similar to the MIT cheetah and was analyzed for trotting forces. Also, a new tendon like support structure was introduced in the hind leg for support. A research by Walter et al. [6] found that the peak trotting forces on the leg are equal to 1.6 times body weight on each leg. Average dog weight is found out to be approximately 40 kilos. Therefore, the total force on each leg would be around 100N. Since, robots are not made to the size of actual animals, we modelled our leg to be four times less than the actual cheetah leg. Also the forces applied on the leg were adjusted accordingly. The Cheetah leg is shown in Figure 1.

The leg is made of ABS. Finite Element analysis was performed on the leg on SolidWorks. A static analysis was done with the newly designed tendon-like support structure with the cheetah leg. It was then compared to the one without any support. The analysis was then repeated on the canine integrated structure. Analysis on a canine leg integrated with a tendon support structure was also done. In addition, the tendon was replaced by a more elastic material to check for any benefits. Magnitudes were varied from 25N to 50N (Factor of Safety=2) to 75N (Factor of Safety=3). The canine leg can be seen in Figure 2.

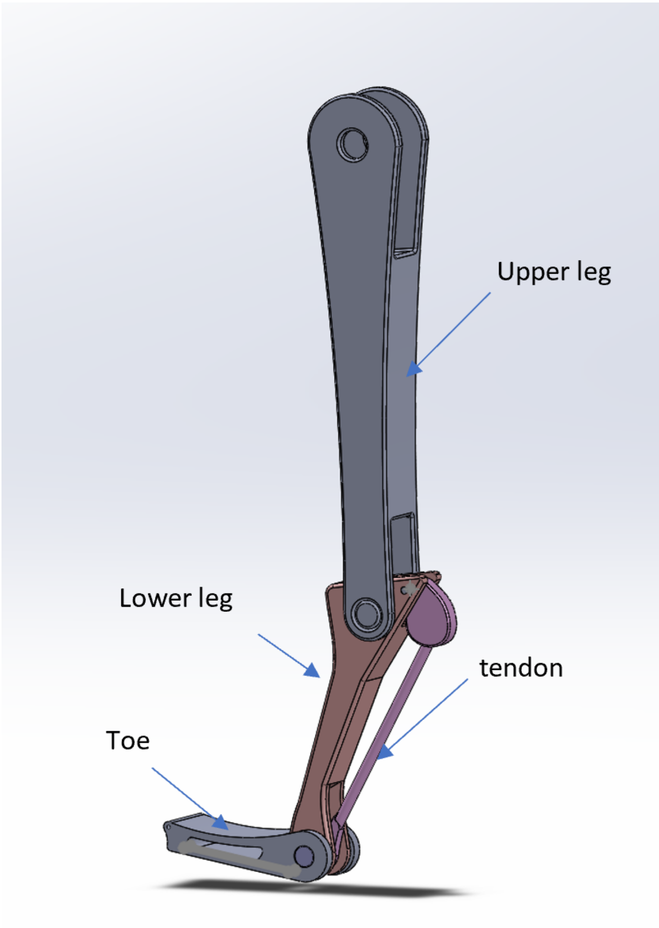

Fig. 1. CAD Model of cheetah leg with a tendon like support

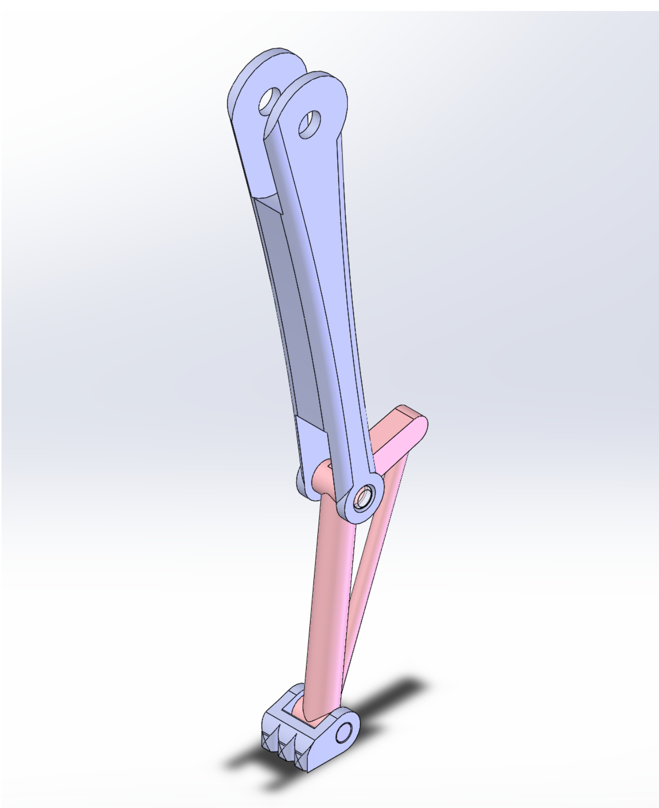

Fig. 2. CAD Model of canine leg with a tendon like support

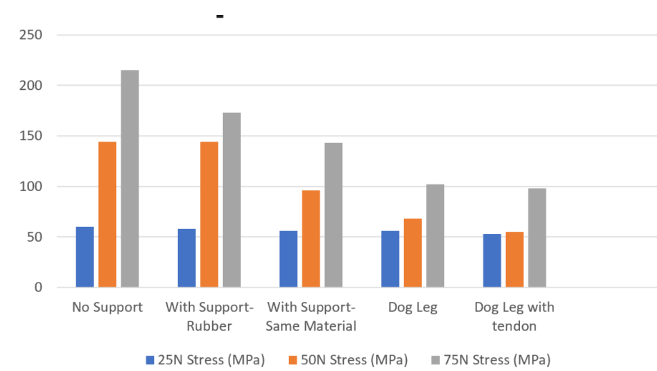

Fig. 3. Stresses experienced by the different Leg Structures

III. RESULTS

The table in Figure 5 shows the data for the FEA done on the five leg structures. No significant changes were seen on loads of 25N. As the load was increased the results became much more apparent. Supports reduce stress more at higher magnitudes. The rubber tendon did not make any significant changes to the strength of the leg at lower loads. But a decrease of 19.5% was noticed at 75N. Adding a support made of the same material reduced the stress by 33% at 50N and 75N. The canine leg performed the best owing to its different leg length and smaller toe. It observed 52.77% and 52.55% less stress than the one with no support at 50N and 75N respectively. Also, the strain as seen in Figure 4 from the lower leg was transferred to the tendon as seen in Figure 5. It decreased by 94% as compared to the support structure made of the same material on the cheetah leg. Addition of a tendon support structure further reduced stresses by 19.11% and 21.56% at 50N and 75N respectively. This is prevalent from the Figure 5.

IV. CONCLUSION

In this research, we have presented a design concept for a quadruped robot leg inspired from a tendon-bone architecture applied at the bone structure subjected to high bending moments. Following this we have also presented a design based on canine morphology as an alternative to conventional designs. We have demonstrated through analysis that these design concepts allow us to significantly improve specific robustness of the leg structures for high-performance mobile robotics as well as for robots not requiring high performance, just normal locomotion. The tendon proved to be more beneficial at higher loads such as in galloping, but still have potential in lower loads. In addition to improving the strength of the leg structure, the tendon also allows for concurrent introduction of compliance and reinforcement in the leg, which have potential implications in energy efficient locomotion. This is due to the potential energy storage capacity of the tendon structure, which can be released during ground contact to improve acceleration. The tendon structure also doubles as an actuator arm for ankle movement.

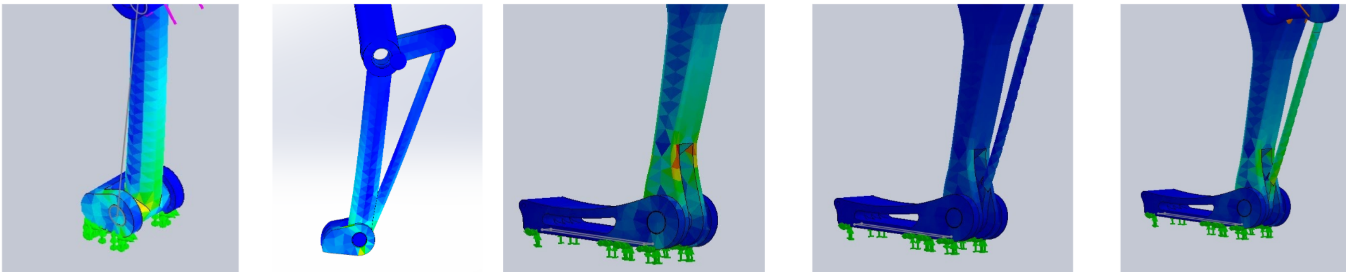

Fig. 4. Strain experienced by the different Leg Structures

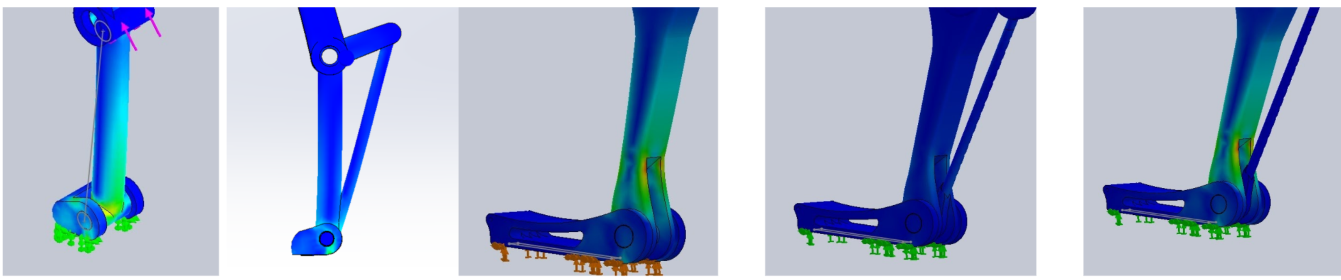

Fig. 5. Stresses experienced by Different Leg Structures

Leg Design	25 N			50 N			75 N		
	Stress (MPa)	Strain	Stress (Tendon)	Stress (MPa)	Strain	Stress (Tendon)	Stress (MPa)	Strain	Stress (Tendon)
No Support	60	2.27E-03	N/A	144	4.54E-03	N/A	215	6.79E-03	N/A
With Support- Same Material	56	2.08E-03	30	96	3.70E-03	61.6	143	5.51E-03	95.3
With Support- Rubber	58	2.26E-03	Negligible	144	4.53E-03	Negligible	173	6.79E-03	Negligible
Dog Leg	56	1.09E-02	N/A	68	2.17E-02	N/A	102	3.22E-02	N/A
Dog Leg with tendon	53	1.70E-02	24	55	0.0187	49.6	128	0.00551	95.3

Fig. 6. Stress and Strain outputs for different Designs

In the future, we plan to conduct dynamic analysis on the newly designed leg to include the wide range of forces experienced by the leg during locomotion. We also plan to conduct a study to characterize the effect of motor torques on the leg structure. Another possible extension of this paper would be to analyze the energy storage capacity of the tendon structure and possibly use it to create efficient jumping/galloping motion.

Acknowledgment

We like to thank the Prof. Kaushik Jayaram for giving us the opportunity to apply the knowledge we acquired in the course into a research project. His guidance was invaluable and this project helped us create a foundation for future research in this field. We would also like to thank our TA, Sagar for all his help and feedback.

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