Biomechanics Background and Initial Specifications:

Team Members: Viraj Kanchan, Nathan Mayer, Shubang Mukund, Matthew Nolan

Bio Inspiration: (5 References, 3 Paragraphs)
Our candidate mechanism was chosen to be a dog due to multiple reasons. Primary reason being the extremely highly and easily available research papers on the subject. Also, with the advancement in robotics multiple researchers have produced functional dog like robots thus making it abundantly clear that the problem is achievable, also it doesn't hurt that in case of us getting stuck we might seek some help/inspiration from the pioneers that have done the work before us. That being said, the team has yet to encounter a dog like canine like robot that is origami based or utilizes the axioms of foldable technology. Thus, keeping the problem challenging. It also helps that various dogs of different breeds have extremely varying sizes, thus giving us enough wiggle room to check for distinctive design configurations.

Identify a candidate organism you wish to focus on its biomechanics. This consists of a specific animal species, its body plan, and the motion of interest. Search in Google scholar, using keywords such as "anatomy", "morphology", "mechanics", "biomechanics", "ground reaction forces", etc. along with the animal's informal or scientific name along with the type of locomotion.

List five of the most closely related research references on topics pertinent to your project, in IEEE format.
Identify three citations which are most useful in creating initial specifications for your robot(use an asterisk in the previous list). Now discuss these three papers, highlighting the information you can draw from each. Be specific. Why is each paper valuable? (At least one paragraph each)

List of Research References:
- Objective Gait analysis[8]
- Three-Dimensional Kinematics of Canine Hind Limbs [1]

Paragraph on Paper 1, etc.

Other Bio-Inspired Robots:

Search for existing bio-inspired robots based on the same animal, subsystem, and motion.

List five of the most closely-related research references on topics pertinent to your project in IEEE format.
Identify three citations which are most useful in creating initial specifications for your robot(use an asterisk in the previous list). Now discuss these three papers, highlighting the information you can draw from each. Be specific. Why is each paper valuable? (At least one paragraph each)

List of Research References:

- Mechanical Construction and Computer Architecture of the Four-Legged Walking Machine BISAM [6]
- Design of a Quadruped Robot Driven by Air Muscles [7]*
- Design and Analysis of Serial Mechanical Leg of Quadruped Lunar Robot [8]*
- Analysis and research of quadruped robot's legs: A comprehensive review[9]*
- Exploiting body dynamics for controlling a running quadruped robot [10]

In the paper, "Design of a Quadruped Robot Driven by Air Muscles", a team from the Biorobotics Laboratory at Case Western Reserve University designed a canine inspired robot, "Puppy", using a series of pneumatic actuators. The team attempted to create a mechanical system based on the biology of a greyhound where each leg in the quadrupedal system is a three degree of freedom structure consisting of a series of revolute joints along a two-dimensional plane. The team indicates the dimensions of the structure while also providing information regarding the maximum and minimum angles for each joint (Table 1, Fig. 1). Although the robotic system that will be built this semester will utilize foldable mechanisms rather than a pneumatic system, the information provided by the "Puppy" design team creates an invaluable source of information for the initial design of the robot. In particular, the foldable mechanisms created can closely mimic the actuation of the joints described in this system including the range of motion achieved by each revolute joint [7].

The paper, "Design and Analysis of Serial Mechanical Leg of Quadruped Lunar Robot", analyzes a bioinspired robot similar to the previous paper to be used in unmanned lunar exploration. The team from the Chinese Academy of Sciences describes the design of their system in great detail, but also outlines the calculation of forces involved as the system moves and the reacting torques required at each joint. The matrices for the system kinematics and resulting Jaconian matrix as described in the paper will prove invaluable when creating the foldable mechanisms for the robot. Therefore, the team will be able to create a similar system and use the predescribed kinematic parameters to calculate relevant quantities such as forces at the end effector and torques at each joint [8].

In the article "Analysis and research of quadruped robot's legs: A comprehensive review," a team from School of Mechanical Engineering, Northwestern Polytechnical University, Xi’an, China collected research results of mechanical legs used by quadruped robots and classified them into three categories (prismatic legs, articulated legs, and redundant articulated legs) according to the degrees of freedom, introduced and analyze them. Based on that, they summarized and studied the design methods of the actuators and mechanical leg structures. They then made some suggestions for the development of quadruped robot’s legs in the future. [9]

Collect all the information you have found from your references into one place. A well-formatted table may do, with supplementary figures from literature as needed. A specifications table is a handy way to collect parameters. Use SI units. Example below:

Table 1: Parameter Specifications for Initial Design

Parameter	Unit	Value Range	Reference
Mass of a Greyhound	Kilograms	27-40	[7]
Minimum Angle: α	Degrees	92	[7]
Minimum Angle: β	Degrees	102	[7]
Minimum Angle: γ	Degrees	106	[7]
Maximum Angle: α	Degrees	180	[7]
Maximum Angle: β	Degrees	170	[7]
Maximum Angle: γ	Degrees	192	[7]

- Typical mass of the animal as a whole, and of key anatomical parts
- Average speed of the animal.
- Key points in a stride: leg motion such as stride length and maximum foot height, trunk motion and orientation, etc.
- Typical ground reaction forces during locomotion(plot is best)
- Metabolic energy/power consumed to locomote (respiration).
- Mechanical energy/power generated during locomotion

- Key biological materials and their mechanical properties (bone, ligaments, tendons, and the resulting link/joint stiffnesses and damping properties)
- Muscle forces

Other Assumptions:

Fill in the information gaps from your biomechanics investigation with informed assumptions you can make. For example, if you know ground reaction forces from your paper, and some masses, try to find peak accelerations. If you know forces and velocities, calculate power usage. If you know maximum jump height and mass, find energy required for a jump. The most important pieces of information you can gather at this point are elements like "how much energy is consumed in accomplishing this gait", "What are the forces involved", etc.

Robot	Weight (kg)	Payload/ weight	Max. speed (km/h)	Year
BigDog	109	0.41	10	2008
HyQ	90.4	—	7.2	2010
LS3	590	0.3	11.2	2011
WildCat	154	—	32	2013
TITAN-XIII	5.2	0.2	3.6	2013
Cheetah-cup	1.1	—	5.1	2013
Spot	75	0.6	—	2015
SpotMini	30	0.47	—	2016

Table 2 : The weight, payload-to-weight ratio, and maximum speed of significant quadruped robots in recent years

Figures:

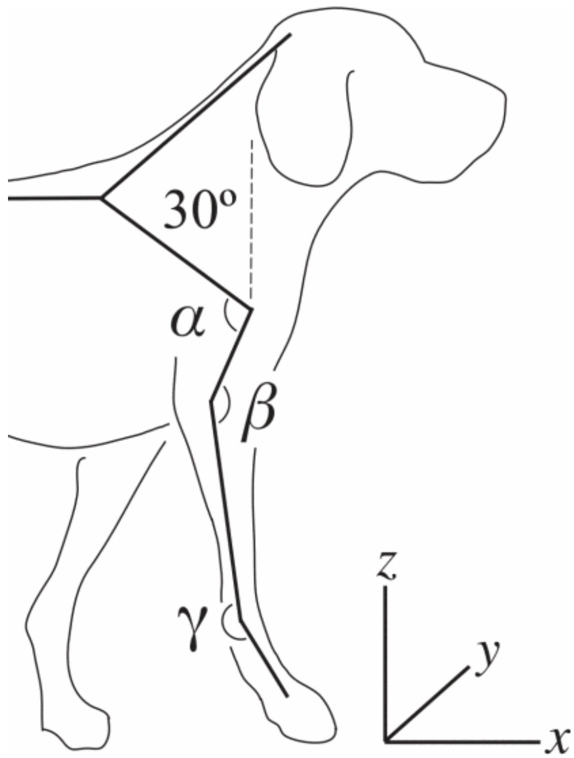

Fig. 1: Depiction of joint placements for the leg of the “Puppy” robotic system designed by the Case Western Reserve University Biorobotics Laboratory [7]

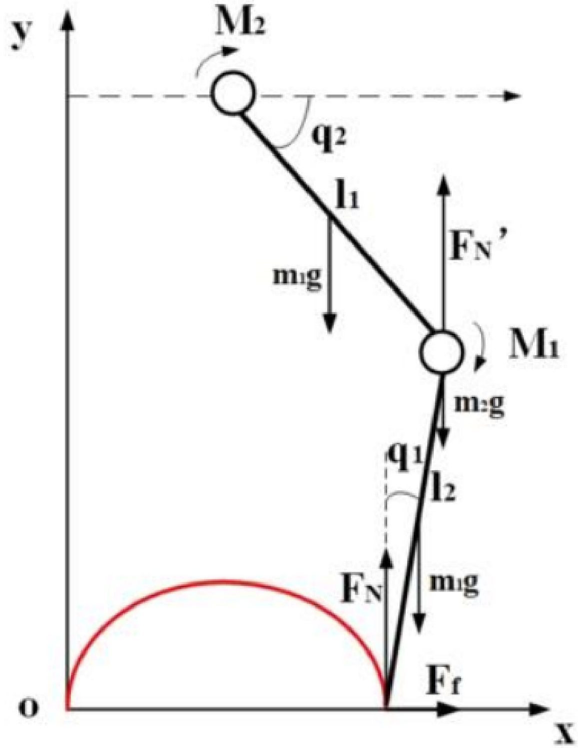

Fig. 2: Force and Moment of the Mechanical Leg [8]

Supply at least two figures from literature, highlighting key aspects of the biological system. This should include one from each of the following categories:

Figures/drawings of skeleton, anatomy, exoskeleton, body plan, musculature, kinematics
Motion plots, freeze frames of gait cycle, plot of ground reaction forces
… other aspects of the parameters above.

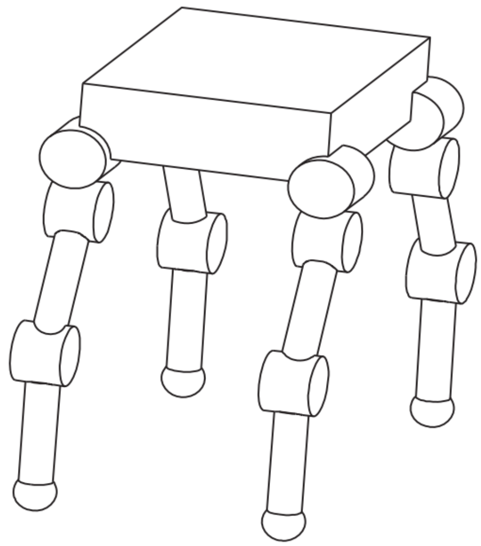

Fig. 3: Mammal-type robot - The joint torque is small when the leg is bent, and there is almost no joint torque when standing upright

Engineering Representation:

Draw the simplest engineering representation of the system you can of your proposed mechanical system. How many rigid bodies are there? How many can be approximated as massless(1/10 of the total mass or less)? Where are the springs? Where is the (main) actuator?

The simplest engineering representation of this system consists of a base body and four limbs, with each limb containing three joints and three links to facilitate the necessary reciprocating motion.

Discussion:

1. Discuss / defend your rationale for the size of the animal you selected in terms of your ability to replicate key features remotely with limited material selection.

Being particularly interested in optimizing quadrupedal gaits, the most obvious choice was to take bio-inspiration from the dog. Part of this decision related to the abundance of research relating to current robotic dogs and the possible novelty of using foldable techniques to construct a dynamical dog system. Given the wide range of dog breeds, the team has relatively high design freedom with regards to the scale of the system to be studied. A small-breed dog would require manageably sized limb mechanisms, and the key features such as limb proportions and joint stiffnesses should be achievable with limited, laminate materials. The joint and link stiffnesses should be reproducible through using stiff laminate links (e.g. thick carbon fiber or fiberglass stack-ups) and joint materials with a tuned flexural stiffness.

2. Find a motor and battery that can supply the mechanical power needs obtained above. Consider that motor efficiencies may be as high as 95%, but if you can't find it listed, assume you find a more affordable motor at 50-70% efficiency. Compare the mechanical watts/kg for the necessary motor and battery vs the animal's mechanical power/mass above? Which one is more energy dense?

Bibliography:

[1] Fischer, M.S., Lehmann, S.V. & Andrada, E. Three-dimensional kinematics of canine hind limbs: in vivo, biplanar, high-frequency fluoroscopic analysis of four breeds during walking and trotting. Sci Rep 8, 16982 (2018). https://doi.org/10.1038/s41598-018-34310-0

[2] K. Berns, W. Ilg, M. Deck, J. Albiez and R. Dillmann, "Mechanical construction and computer architecture of the four-legged walking machine BISAM," in IEEE/ASME Transactions on Mechatronics, vol. 4, no. 1, pp. 32-38, March 1999, doi: 10.1109/3516.752082.

[3] K. S. Aschenbeck, N. I. Kern, R. J. Bachmann and R. D. Quinn, "Design of a Quadruped Robot Driven by Air Muscles," The First IEEE/RAS-EMBS International Conference on Biomedical Robotics and Biomechatronics, 2006. BioRob 2006., 2006, pp. 875-880, doi: 10.1109/BIOROB.2006.1639201.

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