A Novel Approach to Quantify and Compute Gait Analysis Parameters of Quadrupeds

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Abstract: **Gait analysis is the study of human and animal locomotion. Analysis of gait is particularly prevalent in developed countries, owing to extensive capital and resources. However, in developing countries such as India, gait analysis devices and instruments are restricted solely to metropolitan cities. Even in Metropolitan Cities, the analysis of human gait is costly. An analysis of quadruped gait is notably absent in developing countries and, if present, is extremely expensive. This creates a financial disparity, in which those in poverty are unable to have a veterinarian kinematically check their Quadruped's gait, while the wealthy are able to do so. The solution presented aims to analyze the gait of all quadrupeds. This mechanism correlates the usage of a Gyroscope, 3-axis accelerometer, and Digital Motion Processor along with graphs plotted using Python's MatPlotLib Library and three-dimensional simulations with an AutoCAD model and simulated using the library Panda3D in a portable, wearable device. The Quadruped is made to wear the device and walk a specific number of steps. The angular data is collected through the MPU6050 sensor, which is then translated into a report comprising the raw angular data, Symmetry, gait, and stride tables, supplemented by a 3D simulation of the quadruped gait.**

Keywords: Gait analysis, quadrupeds, arthritis in quadrupeds

I. Introduction

Gait analysis is the systematic study of animal locomotion, using the eye and the brain of observers, augmented by instrumentation for measuring body movements, body mechanics, and the activity of the muscles [1]. With no known complications [2], Gait analysis assists in identifying specific gait deviations and the causes of the abnormalities [3]. Gait deviations may be due to impairments such as muscle weakness, abnormal muscle tone, static or dynamic muscle contracture, abnormal joint position, or reduced range of motion. Gait analysis helps differentiate the patients' primary abnormalities, secondary abnormalities, and compensatory strategies [4]. It is also used to monitor the progression of neuromuscular diseases, plan surgical procedures [5], evaluate postoperative outcomes [6], recommend nonsurgical intervention [7], and assess the effects of orthoses and prostheses [8]. In the literature there are many research papers that records the development of many IoT based devices [29][30][31]

The present study was inspired by the lack of technical resources available for veterinarians to accurately, precisely, and cost-effectively analyze quadruped gait.

There are two primary types of gait analysis:

1. Observational Gait Analysis (OGA)
2. Quantitative Gait Analysis

Observational gait analysis is data gleaned by observing a patient; quantitative gait analysis is data collected electronically [9].

Observational Gait Analysis analyses a patient's gait through either the use of the clinician's unassisted observation or with assistance through slow-motion video replay or freeze-frame techniques to record the gait. A clinician uses visual cues to compare asymmetries and find abnormalities. Despite the video being superior to unassisted observation, OGA relies on the experience of the clinician and therefore is subject to bias and limited precision

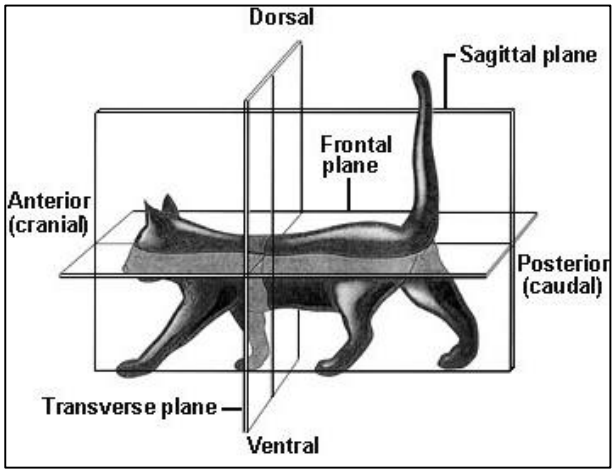

Figure 1 – Anatomical Terms for Quadrupeds [10]

Furthermore, natural biases and tendencies, such as focusing solely on the sagittal, transverse or frontal planes, lead to misinterpretations. (The three planes that divide a quadruped animal are as follows: the *sagittal plane* divides the body into right and left sides; a *transverse plane* divides the body into anterior and posterior portions, and a *frontal plane* divides the animal into dorsal and ventral halves [11]. Moreover, observing multiple body segments simultaneously acts as a limitation.

On the contrary, Quantitative Gait Analysis uses instruments and devices to measure the Temporal-Spatial, Kinematic and Kinetic data that cannot be gathered solely by observation.

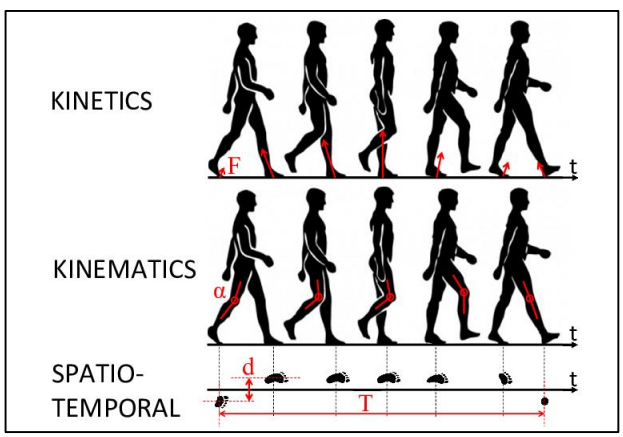

Figure 2 – Different Types of Quantitative Gait Analysis in Humans [12]

The timing and spacing of foot strike and foot off gait events are used to generate Spatio-temporal gait data. These measurements can be used to calculate velocity, cadence, stance and swing time, stride length, and a number of other important gait metrics.

Kinematics is the study of joint motion without regard for the forces that cause the motion. Kinematic data, which describes the motion of the lower extremity joints during the gait cycle, is widely used in the analysis of gait pathology. It does not, however, provide information on biomechanical efficiency, joint torques, or ground reaction forces.Kinetic data is the relationship between the causes of motion and the motion itself. Kinetic data includes measurements such as the Center of Force (CoF), the External Force (GRF), and the Center of Gravity (CG) (CoG). The resultant joint forces can be calculated by combining kinematic and kinetic data.

Today, quadruped gait is either measured purely visually, which is subject to extreme human error due to its non-statistical nature, or using pressure mats, which, despite being accurate, require a large area to settle and collate effectively and are not portable. Besides, the pressure mats are extremely expensive and are only available in developed countries for specific purposes such as gait analysis of elite racehorses and military guard dogs. The objective was to make a portable gait analysis tool that revolutionizes gait analysis for all quadrupeds, from buffalos to horses to pet animals. The motivation behind this research paper is to reduce the economic disparity in the gait analysis of animals.

With Quantitative Gait Analysis being reserved for the absolute elite of the society, those with extraordinary purchasing power, the average person is forced to resort to Observational Gait Analysis, which, despite being comparatively affordable, is highly subjective as it is solely dependent on the vision, capability, experience, and expertise of the veterinarian. Furthermore, it does not take into account any statistics to complement the subjective proficiency of the veterinarian. This prevents the veterinarian from getting to the fundamental essence of the problem at hand, which in turn results in a faulty diagnosis, which consequently may lead to a life full of pain or even an early death for the Quadruped.

PortAGait aims to calculate the joint angles of a quadruped through Inertial Measurement Unit (MPU6050) sensors, generate a printable, objective report through Python and the MatPlotLib Library, thereby providing a statistical insight into quadruped gait, and provide a visual simulation of the gait to facilitate remote analysis.

A. Motivation and Novelty

PortAGait is the first of its kind. It is an extremely small, comfortable, and portable device that will enable Veterinarians to kinematically analyze the gait of all sizes of quadrupeds - from racehorses to pet dogs. Solely four straps on the joints of quadrupeds will quantify the animal's gait in the form of quaternion angles, effectively enabling veterinarians to analyze quadruped gait kinematically.

The uniqueness of PortAGait is reflected in the fact that anyone with little to no knowledge of technology can easily set the device up and use it to analyze the gait of the Quadruped statistically. Furthermore, it is an extremely small device, with the main Arduino in a box of length 8.3 cm, breadth 7.1 cm, and height 4.0 cm. The IMU Sensors are enclosed in an even smaller box of length 2.7 cm, breadth 2.15 cm, and height 0.95 cm.

The essence of PortAGait also lies in the simulation and its graph and report generation features, which make the statistical analysis process easier for the Vet. As 70% of gait lameness is undetectable by the human eye, it will save all quadrupeds from a life full of pain.

The remainder of the paper is organized in the following way. Section II describes the prototype developed for the study. Section III describes the problem statement to tackle by the PortAGait. Section IV is the results and discussion that discusses the result obtained and finally section V is the conclusion and future scope that concludes the research paper and briefly speaks about the future prospect of the PortAGait.

II. The Prototype

PortAGait - The Prototype of a Portable Device to Quantify and Compute Gait Analysis Parameters of Quadrupeds – was created to solve the existing problem. Numerous hardware and software components were amalgamated to create this complex yet straightforward circuit with the objective of reducing and ultimately demolishing the economic disparity present today.

A. Hardware

The hardware components with the corresponding number utilized are stated below:

1. Arduino Uno – 2
2. Arduino Nano – 1
3. Inertial Measurement Unit MPU6050 Sensor – 4
4. Radio Frequency (nRF24L01) Module – 3
5. TP4056 1A Standalone Linear Li-Ion Battery Charger – 2
6. 3.7 V to 5V DC to DC Booster – 2
7. 3.7 V 2800 mAh Battery – 2
8. 3D Printed Cases

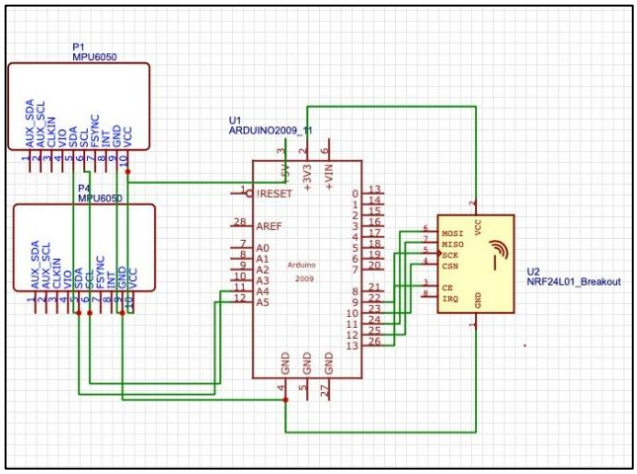

Figure 3 – Transmitting Device Circuit

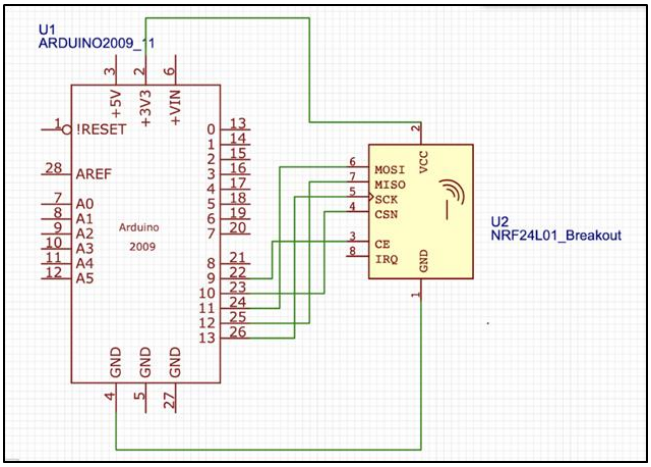

Figure 4 – Receiving Device Circuit

a) Arduino Uno: Arduino UNO is a microcontroller board based on the ATmega328P. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header, and a reset button [13].

In PortAGait, Arduino Unos served as the main microcontrollers, collecting and transmitting data received by the IMU sensors to the Arduino Nano connected to a computer.

b) Arduino Nano: Arduino Nano is a small, complete, flexible, and breadboard-friendly Microcontroller board, based on ATmega328p, developed by Arduino.cc in Italy in 2008 and contains 30 male I/O headers, configured in a DIP30 style. Arduino Nano Pinout contains 14 digital pins, 8 analog Pins, 2 Reset Pins & 6 Power Pins [14].

In PortAGait, Arduino Nano is connected to a computer to receive data transmitted by the Arduino Unos placed on the Quadruped.

c) MPU6050 IMU Sensor: An Inertial Measurement Unit (IMU) is a device that can measure and report the specific gravity and angular rate of an object to which it is attached. An IMU typically consists of Gyroscopes and Accelerometers [15].

The MPU6050 is a Micro Electromechanical System (MEMS) that includes a three-axis accelerometer and a three-axis gyroscope. It can measure velocity, orientation, acceleration, displacement, and other motion-related characteristics [16].

Using Arduino Programming and the SparkFun MPU-9250 Digital Motion Processor (DMP) Arduino Library, the IMU sensors were programmed to calculate, collect and collate the quaternion angles of the joint of the Quadruped.

d) Radio Frequency (nRF24L01) Module: nRF24L01 is a single chip radio transceiver for the worldwide 2.4 - 2.5 GHz ISM band. The transceiver consists of a fully integrated frequency synthesizer, a power amplifier, a

crystal oscillator, a demodulator, a modulator, and Enhanced ShockBurst protocol engine [17].

Three nRF24L01 modules were utilized in PortAGait. Two modules were used to wirelessly transmit the angular data collected by the Inertial Measurement Unit sensors through the Arduino Uno microcontrollers. One Module was connected to a computer to receive the transmitted data instantly.

e) TP4056 1A Standalone Linear Li-Ion Battery Charger: The TP4056 is a complete constant-current/constant-voltage linear charger for single-cell lithium-ion batteries. The TP4056 is ideal for portable applications due to its low external component count and SOP package [18]. TP4056 was used to protect PortAGait from under as well as overcharging.

f) 3.7V to 5V DC to DC Booster: The battery utilized in PortAGait had a potential difference of 3.7V, while that required by Arduino Uno is 5V. A 3.7V to 5V DC to DC booster was used to overcome this.

g) 3.7V 2800 mAh Li-ion Rechargeable Battery: A lithium-ion battery is a type of rechargeable battery in which lithium ions move between the negative (anode) and positive (cathode) electrodes to charge and discharge the battery [19]. Two 2800 mAh batteries enabled PortAGait to become portable while being able to work for hours on end.

h) 3D Printed Cases: A carefully designed 3D Printed case amalgamates the complex yet straightforward circuit of PortAGait, holding it in place.

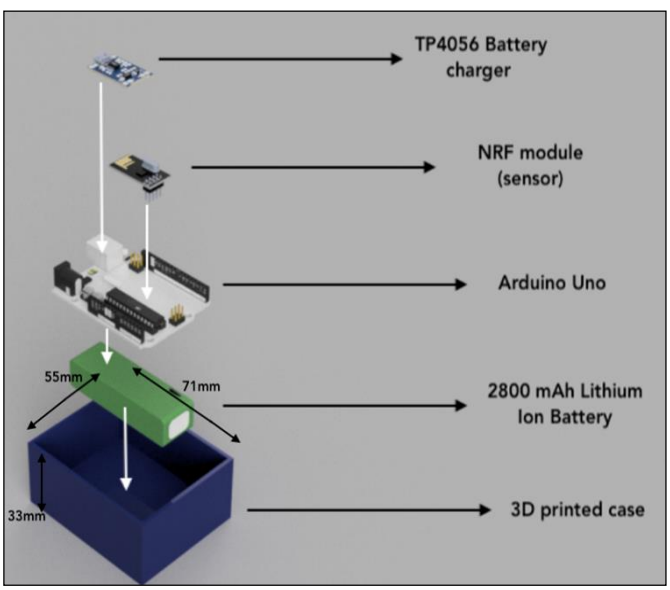

Figure 5 – Transmitting Diagram

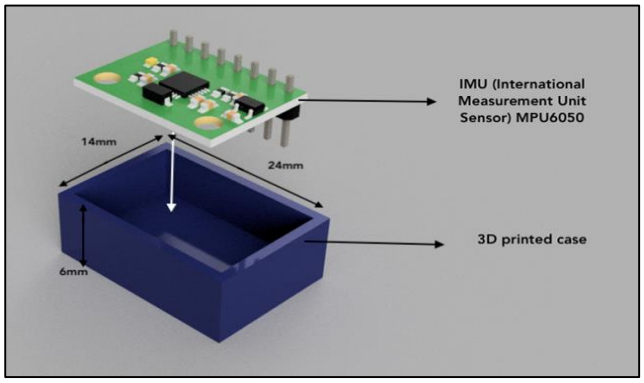

Figure 6 – Sensor Diagram

B. Software

The **software** used for data collection, analysis, and report generation is listed below:

1. Arduino IDE
2. Autodesk Fusion 360
3. Python
    1. MatPlotLib Library
    2. Panda3D

a) Arduino IDE: The Arduino IDE (Integrated Development Environment) is an open-source software created by Arduino.cc that is primarily used for writing, compiling, and uploading code to nearly all Arduino Microcontrollers [20]. It was used to calibrate and program IMU sensors and the nRF24L01 Module to work cohesively as PortAGait.

b) Autodesk Fusion 360: Fusion 360 is a commercial computer-aided design, manufacturing, computer-aided engineering, and printed circuit board design software application developed by Autodesk [21]. Fusion 360 was used to design the 3D Quadruped to simulate it using the collected angular data in the Panda3D library. This enables remote analysis.

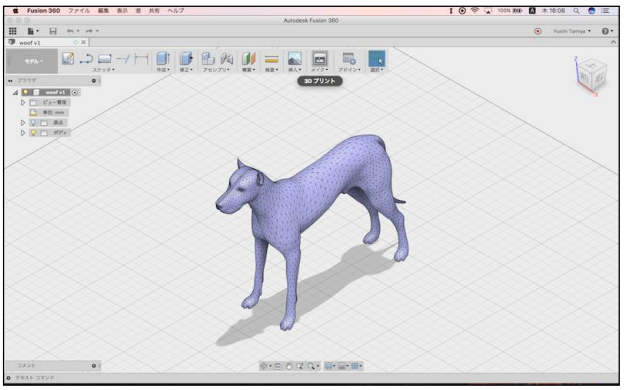
Figure 7 – An image showcasing one of the Quadruped Designs made on AutoCAD Fusion 360

c) Python: Python is an interpreter, interactive, object-oriented programming language. It incorporates modules, exceptions, dynamic typing, high-level dynamic data types, and classes. Its design philosophy prioritizes code readability by employing significant indentation [22].

d) MatPlotLib: Matplotlib is a comprehensive Python library for creating static, animated, and interactive visualizations [23]. The MatPlotLib library was used to generate graphs from the raw angular data received from the IMU Sensors.

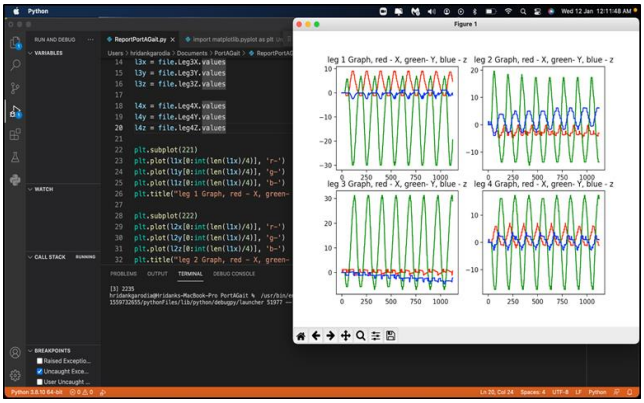

Figure 8 – MatPlotLib Library with Graphs

e) Panda3D: Panda3D is an open-source engine for real-time 3D games, visualizations, simulations, and experiments [24]. Panda3D helped simulate the angular data into the 3D-designed Quadruped.

III. Case Study

Today, quadruped gait is either measured purely visually, which is subject to extreme human error due to its non-statistical nature, or using pressure mats, which, despite being accurate, require a large area to settle and collate effectively and are not portable. Besides, the pressure mats are extremely expensive and are only available in developed countries for specific purposes such as gait analysis of elite racehorses and military guard dogs. The objective behind PortAGait was to make a portable gait analysis tool that revolutionizes gait analysis for all quadrupeds, from buffalos to horses to pet animals. The motivation behind this research paper is to reduce the economic disparity in the gait analysis of animals.

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Arthritis is a progressive disease in dogs and numerous other quadrupeds, similar to humans, for which there is no known cure. Cartilage is a slippery substance that serves as a buffer or "cushion" between the bones of a joint. It enables the bones to move over or around one another without causing pain. Arthritis develops when the cartilage in a joint is damaged. An arthritic joint eventually becomes inflamed and painful [25. That is why prevention and protection of the Quadruped's joints early on through diet and exercise is vital to ensure a healthy, lengthy life. Statistical analysis renders this possible.

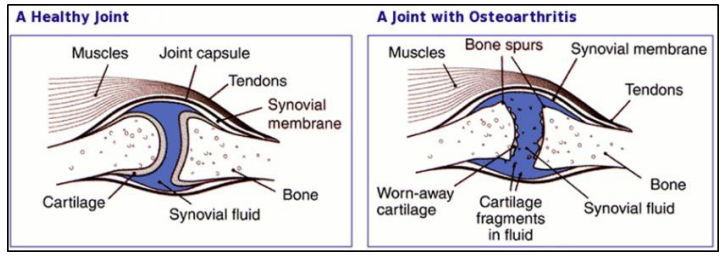


Figure 9 – Diagrammatic Representation of Arthritis [26]

Symptoms of arthritis include limping, reduced mobility, abnormal posture, reduced activity, muscle atrophy, reluctance to play, etc.

A study in 2002 concluded that 90% of cats over 12 years of age had evidence of degenerative joint disease. For example, dogs can show signs of arthritis as early as one year of age. The degenerative joint condition can be found in 20% of dogs before their first year and 80% of more senior dogs at or over age 8 [27], primarily due to a lack of resources to correctly identify arthritis through statistical differences between joint flexions and extensions of each limb.

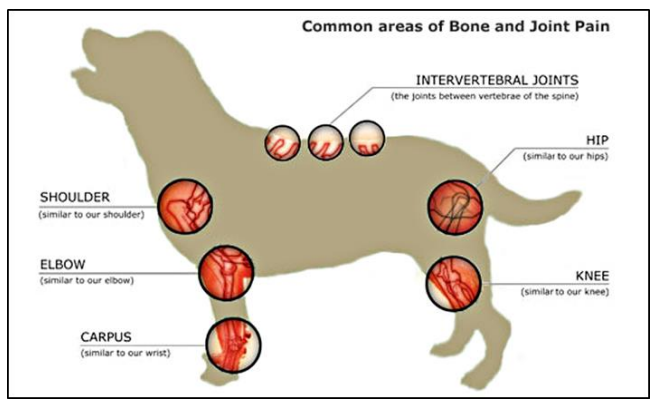


Figure 10 – Image showcasing the various possible areas of arthritis

Because arthritis commonly develops with age, pet owners may misinterpret changes in their animal's behavior (such as a decrease in play) when the animal is actually suffering from severe arthritic pain. Catching arthritis early is the best way to stop it from becoming severe.

These problems were certified by requesting help from pioneers in the field of animal gait and zoology. PETA (People for the Ethical Treatment of Animals) was contacted to collect statistics based on the problem at hand. All collected data certified the lack of technical resources prevalent in developing countries, leading to the ideation, creation, and fabrication of PortAGait - The Prototype of a

Portable Device to Quantify and Compute Gait Analysis Parameters of Quadrupeds.

As PortAGait was developed amid the pandemic-induced lockdown in 2020, testing it on animals at that point in time became difficult. Numerous NGOs were contacted, all of whom expressed concern about coming in physical contact. To overcome this problem, a LEGO Model to mimic linear quadruped gait was built to test PortAGait.

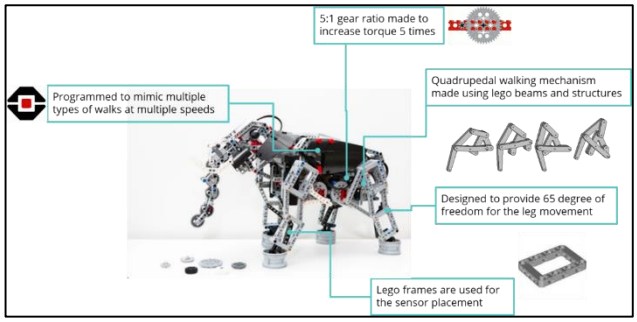


Figure 11 – Principles utilized in mimicking linear quadruped movement through LEGO

The model was carefully designed to mimic actual linear quadruped movement - using 5:1 gear ratios for higher torque and a 65-degree angle of motion. Furthermore, EV3 was programmed to move at different speeds instead of a uniform motion. This served as our initial testing model. This testing led to the conclusion that PortAGait is accurate. Furthermore, it was determined that **at least 25 steps per limb** would be required for practical analysis. On relaxations of Covid protocols, PortAGait was tested on a buffalo's calf and numerous breeds of dogs to ensure its real-world capabilities.

IY. Results And Discussions

In this section of the paper, a small description of the result obtained by analysing the gait by PortAGait.

A. Results

- A strategic combination of Arduino Uno and Nano serves as the microcontrollers.
- The IMU Sensors from each leg collect the joint angles' data and send it to the computer through the nRF modules.
- Upon receiving this data, a Python code simulates it to show the actual joint movements of the canine.
- Another Python code processes the provided data into graphs to enable a Veterinarian to perform statistical gait analysis.
- The circuit is enclosed in a 3D printed case - designed keeping in mind animal comfort and satisfaction.

PortAGait provides:

- ➢ A visual 3D simulation
- ➢ A Printable Report of the Angular Data collected, consisting of:
  - ○ Raw Data, processed into:
    - ■ Gait Table
    - ■ Stride Table
    - ■ Symmetry Table

Graphs arising from the raw data

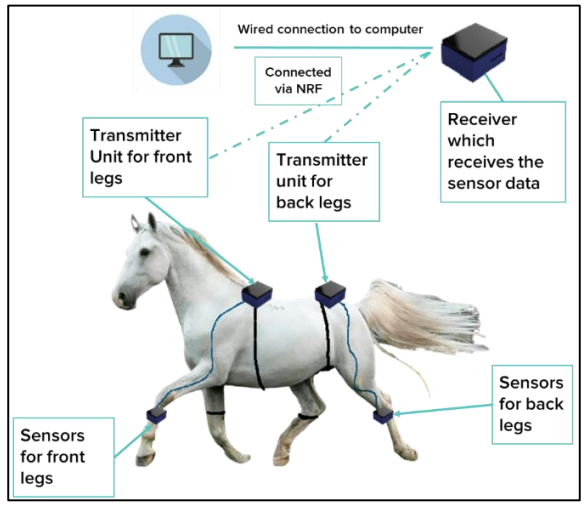
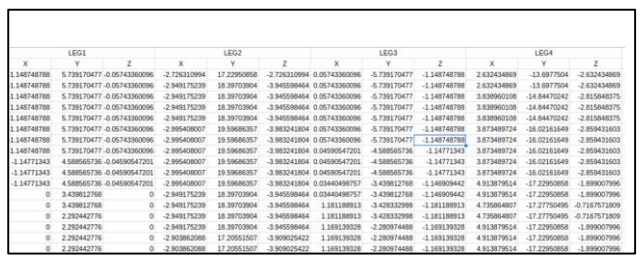


Figure 12 – Image showcasing the orientation of PortAGait



LEG1			LEG2			LEG3			LEG4		
X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
1.148748788	5.739170477	-0.05743360096	-2.726310994	17.22950858	-2.726310994	0.05743360096	-5.739170477	-1.148748788	2.632434869	-13.6977504	-2.632434869
1.148748788	5.739170477	-0.05743360096	-2.949175239	18.39703904	-3.945598464	0.05743360096	-5.739170477	-1.148748788	2.632434869	-13.6977504	-2.632434869
1.148748788	5.739170477	-0.05743360096	-2.949175239	18.39703904	-3.945598464	0.05743360096	-5.739170477	-1.148748788	3.838960108	-14.84470242	-2.815848375
1.148748788	5.739170477	-0.05743360096	-2.949175239	18.39703904	-3.945598464	0.05743360096	-5.739170477	-1.148748788	3.838960108	-14.84470242	-2.815848375
1.148748788	5.739170477	-0.05743360096	-2.949175239	18.39703904	-3.945598464	0.05743360096	-5.739170477	-1.148748788	3.838960108	-14.84470242	-2.815848375
1.148748788	5.739170477	-0.05743360096	-2.995408007	19.59686357	-3.983241804	0.05743360096	-5.739170477	-1.148748788	3.873489724	-16.02161649	-2.859431603
1.148748788	5.739170477	-0.05743360096	-2.995408007	19.59686357	-3.983241804	0.05743360096	-5.739170477	-1.148748788	3.873489724	-16.02161649	-2.859431603
1.148748788	5.739170477	-0.05743360096	-2.995408007	19.59686357	-3.983241804	0.04590547201	-4.588565736	-1.14771343	3.873489724	-16.02161649	-2.859431603
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-1.14771343	4.588565736	-0.04590547201	-2.995408007	19.59686357	-3.983241804	0.04590547201	-4.588565736	-1.14771343	3.873489724	-16.02161649	-2.859431603
-1.14771343	4.588565736	-0.04590547201	-2.995408007	19.59686357	-3.983241804	0.03440498757	-3.439812768	-1.146909442	4.913879514	-17.22950858	-1.899007996
0	3.439812768	0	-2.949175239	18.39703904	-3.945598464	0.03440498757	-3.439812768	-1.146909442	4.913879514	-17.22950858	-1.899007996
0	3.439812768	0	-2.949175239	18.39703904	-3.945598464	1.181188913	-3.428332998	-1.181188913	4.735864807	-17.27750495	-0.7167571809
0	2.292442776	0	-2.949175239	18.39703904	-3.945598464	1.181188913	-3.428332998	-1.181188913	4.735864807	-17.27750495	-0.7167571809
0	2.292442776	0	-2.949175239	18.39703904	-3.945598464	1.169139328	-2.280974488	-1.169139328	4.913879514	-17.22950858	-1.899007996
0	2.292442776	0	-2.903862088	17.20551507	-3.909025422	1.169139328	-2.280974488	-1.169139328	4.913879514	-17.22950858	-1.899007996
0	2.292442776	0	-2.903862088	17.20551507	-3.909025422	1.169139328	-2.280974488	-1.169139328	4.913879514	-17.22950858	-1.899007996

Figure 63 – Raw Data collected using the IMU Sensors

B. 3D Simulation

A 3D simulation helps a veterinarian look at the motion from all angles. Furthermore, this will prove to be extremely useful for remote analysis when the Vet and the Quadruped are not in direct contact. In its future stages, PortAGait may even be able to show the basic joint movement.

- ➢ Printable Report, consisting of:
  - o Raw Data, processed into:
    - ▪ Gait Table - Provides basic Gait Parameters
    - ▪ Stride Table - Provides stride time, length, and velocity
    - ▪ Symmetry Table - Provides a ratio of Stride velocity, length, and time of legs to analyze Gait Symmetry

  - o Graphs arising from the raw data: The graphs provide more critical information about the uniformity of the Gait Cycle.

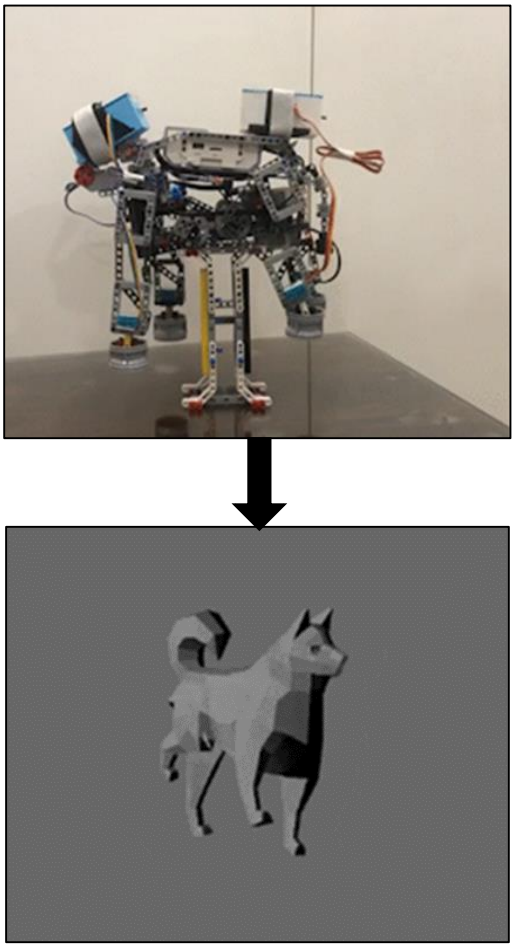

Figure 74 – LEGO simulation to 3D Simulation

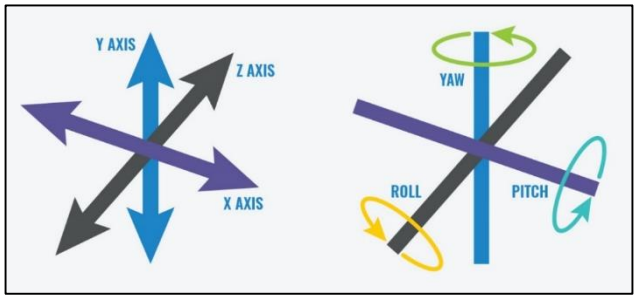

Figure 85 – Image showcasing Yaw, Pitch, and Roll [28]

X-axis - Roll (sideward Deflection) - Blue in graph
Y-axis - Pitch (Primary) - Red in graph
Z-axis - Yaw (Angular Deflection) - Yellow in graph

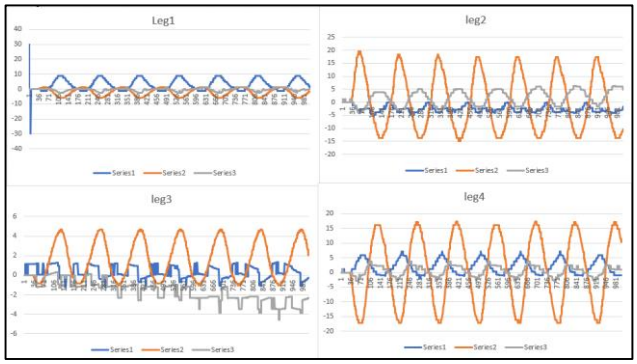

Figure 96 – Abnormal Values

Given above is an example of the graphs in case of abnormal motion. It can be identified that alternative legs are moving at differing speeds, and the legs are not in sync with one another. The red color represents forward movement.

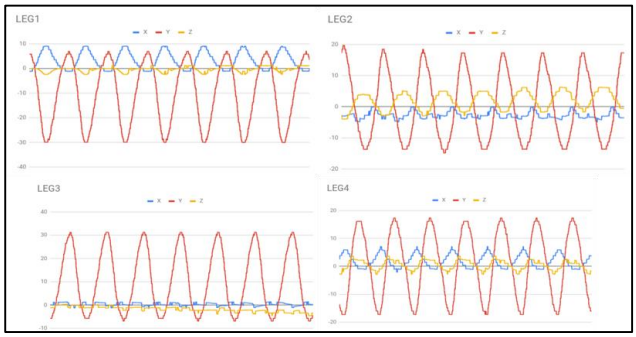

Figure 107 – Normal Values

Given above is an example of a perfectly normal gait. The legs move simultaneously, and the alternate legs are in sync. Here, the red color represents the forward movement. This enables the veterinarian to spot gait deformities easily.

V. Conclusion And Future Scope

There are many researchers who are working in the field of gait analysis of the quadrupeds. Although they have designed many devices but there is still very few number of gadgets that can be used to monitor analyse the gait of any size quadrupeds from race horses to pet dogs. In order to achieve the objective of the research paper, a hand held pocket stored device is developed and named it as PortAGait. The Device comprises of Arduino Uno, Arduino nano, IMU sensors and Radio Frequency modules. The IMU sensors collects the joint angle data which are then passed to the computer through the nRF modules. The angle data are used by a Python code to simulate the movements of the quadrupeds. This simulation helps to perform statistical gait analysis. The useful features of the PortAGait are as follows:

- Statistical graphs give an insight into the 'uniformity' of the measured gait.
- In its further stages, CAD simulation will provide for remote analysis by simulating the estimated joint movement.
- Gait, Symmetry, and Stride tables provide basic gait parameters.
- The design of the device is such that it can be used to all size quadrupeds.

During the testing and the prototyping stages the accuracy of PortAGait is 79% which can be further increased by further testing. However, due to an incorrect placement of the PortAGait may lead to simulation errors

and inaccurate results. This errors can be rectified by the generation of the objective report which helps to identify the minor errors in the gait while the 3D simulation and helps the veterinarian to remotely monitor all gait angles. In the future, to build on this similar prototype, it is planned to add more IMU sensors for more accuracy, decrease the size of the electronic circuit, and collect and make databases of Animals to offer an AI model that can compare the normality and abnormality on its own. To conclude, it is firmly believed that this solution is novel and has the potential to be a beneficial solution in understanding the walking anatomy of any animal. It also opens the door to the remote diagnosis of animals - in places with a small number of veterinary hospitals. Furthermore, it tackles the concern of transport of such animals to labs.

CONFLICT OF INTEREST

The authors would like to declare that there is no conflict of interest in executing the present study and developing the prototype

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