WOOFlex: A Wearable Device to Aid Canine Flexibility Exercises

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ABSTRACT

Flexibility and stretching exercises for dogs are used to improve joint motion and alleviate limb pain. However, there is a lack of information in the effectiveness of these canine exercises when performed by dog owners and caregivers. Current solutions for measuring range of motion are not designed to be worn by dogs. In order to evaluate the position of a joint at any given time, the user, the human assisting the dog in the exercises, must hold a digital or analog device while performing the exercise without real-time feedback associated with the dog's breed or joint exercised. We propose WOOFlex: a wearable that assists in canine flexibility exercises that (1) is attached to the dog's limbs so as to not interfere with the exercise, (2) includes IMU sensors to measure the joint angle, and a web application to (1) provide real-time visual and audio feedback for assisting the user in not exceeding safe joint angle ranges, and (2) to store exercise session data to monitor the flexibility progress.

CCS CONCEPTS

• **Human-centered computing → Interaction devices**; **Interactive systems and tools**.

KEYWORDS

Animal-Computer Interaction, IMU, Wearable technology

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1 INTRODUCTION

Range of motion and flexibility exercises are commonly part of rehabilitation programs in dogs recovering from surgery in rehabilitation programs [5, 6], competitive training, and becoming popular in dog care journals, and magazines [12]. However, when performed, stretching exercises may be inaccurate as they mostly rely on the ability of dog owners to deliver care while monitoring the dogs' response. Veterinary professionals may give out guidelines and suggested exercises that caregivers can do with the dogs to improve their state of flexibility, for cases where the dog is in rehabilitation, but that guidance often only provide estimates of adequate exercise procedures [11]. For example, the owner is instructed to "watch for signs of discomfort" or note "abnormal changes" in joints and skin, but there are no metrics stating what is abnormal or at least typical for dogs. We based this research on previous work that presented dogs' estimated flexion and extension angles of the specific joint or dog breed [4]. These angle measures are highly quantitative and difficult to monitor while doing the exercises, particularly for untrained individuals. In addition, the current way to measure flexion and extension of joint mobility is primarily through a universal plastic goniometer. It would be taxing for someone untrained to conduct measurements while performing the exercises with their dog since the plastic goniometers have to held in a specific position and manual annotation log per measurement are required.

We propose WOOFlex: a wearable device attached to the limbs that assists flexibility exercises by the use of IMUs for measuring range of motion and joint angle, and an integrated application which provides real-time feedback of the angle measurements by joint location and breed our web application uses past research data to help the human perform the exercises correctly, and stores the session's data for tracking the dogs' improvement. Our goal in this project is to reduce the load of multiple areas of focus on the human and to better support the animal by digitally implementing appropriate flexibility measures in a wearable. We envision a tool that could be helpful for both caregivers and veterinary professionals to monitor and aid a dog's progress and protecting the dog's healthy range of motion.

2 RELATED WORK

In regards to the electronics we used, IMU sensors appear as an option to measure joint angles due to their small size and lightness. Previous work has used IMUs in wearable to identify and monitor dog activities such as gesture activity recognition in working dogs to enable two-way communication between humans and dogs [10]. This project use accelerometer data and Machine Learning tools to predict postures and gestures such as spin, jump or roll over. Another project compares the use of IMUs and optical data to perform joint angle measurement in different joints during gait analysis in dogs and concludes that IMU data is feasible for joint

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angle measurement [7]. To our knowledge, these sensors have not yet been used for canine flexibility exercises.

Many veterinary practices use equipment to assist in treatment, such as slings, which are used to provide support to the dog in walking exercises [1]. Additionally, life vests are used in hydrotherapy to assist in dog's safety in the tub [1], and orthopedic braces for joint support used by dogs after surgery[8]. We propose to implement an electronic goniometer using IMU sensors in a brace to aid in flexibility activities. To ensure the wearable portion is suitable for dogs, we will be using an orthopedic brace created for dog limbs [3].

3 IMPLEMENTATION

For our implementation of WOOFlex, we adapt orthopedic braces to embed electronics. The electronic goniometer senses the joint angle while exercising using IMU sensors, and an application wirelessly connects to the electronics through Bluetooth and provide data to support the user when the exercises are performed.

3.1 Form Factor

Orthopedic braces made for dogs are used as the base for our two 3D printed cases. One case contains an Arduino and LED, and it is placed above the joint, another contains the IMU and is placed below the joint (See Fig. 1), this ensures that the wearable would be form fitting to dogs and appropriate for dogs. These braces come in various sizes, so our prototype can be fitted on dogs of various sizes. However, as of now, due to the size of the electronics, it works best on medium or larger dogs. The device could be attached to the limb using hook and loop fastener (Velcro) straps. This design avoids measurement errors that could happen due to a wrong position of the IMUs on the limbs, allows adaptability to different joints, and does not obstruct the joint's movement or the user hand's position when holding the dog's limb. All dogs were monitored throughout the exercise to ensure that the dog is not experiencing any discomfort. Also, the device is made to accommodate other ways of monitoring in future iterations of the project.

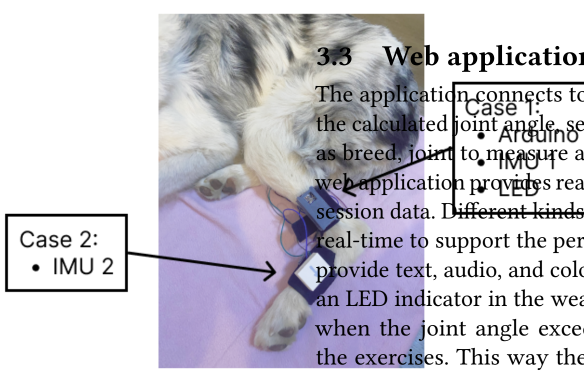


Figure 1: Border Collie wearing WOOFlex on his ankle.

3.2 Electronic Goniometer

We developed the EG using an Arduino Nano 33 BLE fitted with a Bluetooth Low Energy module and two 9-DOF IMUs (1 MPU9250 and 1 LSM9DS1), each having a 3-axis accelerometer, gyroscope, and magnetometer. Once the sensors are calibrated and placed, one above the joint and the other below the joint (2), we follow these steps to calculate the joint angle: 1) The Arduino collects raw IMU data (3-axis acceleration, angular velocity and magnetic field) to the Arduino Nano using the I2C protocol, 2) The raw data is cleaned using the Madgwick filter algorithm to calculate each IMU orientation represented as a 3D Euler orientation: pitch (θ), roll (φ) and yaw (ψ), 3) Using each IMU orientation a 3D vector (x_i, y_i, z_i) per IMU is formed, 4) We obtain the angle (0-360°) between these two 3D vectors, representing the joint angle , and 5) finally, this angle is sent to the web application via Bluetooth.

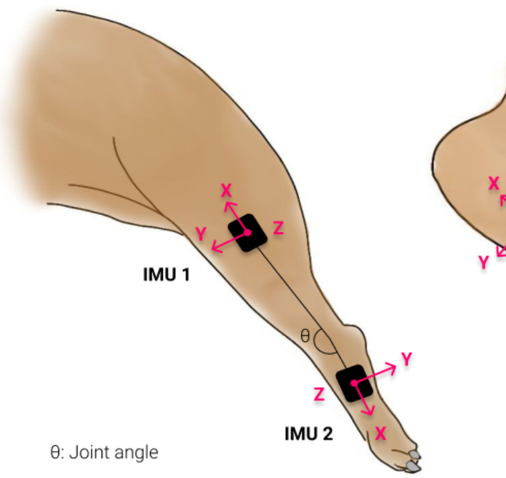


Figure 2: IMUs positioned in a flexed and extended joint

3.3 Web application

The application connects to the wearable by Bluetooth to receive the calculated joint angle, sets the exercise session parameters such as breed, joint to measure and number of repetitions needed. The web application provides real-time feedback and stored access to the session data. Different kinds of feedback (See Fig. 3) are provided in real-time to support the performance of the exercise correctly. We provide text, audio, and color feedback through the app, as well as an LED indicator in the wearable. The audio feedback is triggered when the joint angle exceeds the expected angle range during the exercises. This way the user is alerted to the dog's potential limits on flexibility. The audio feedback changes its speed (beats per minute) according to how close the current joint angle is to the maximum or minimum angle recommended by that breed and joint. Audio feedback provides a bigger sense of urgency when the angle is closer to the limits of the range set. Visual feedback of the angle measured is displayed on the web application. The angle changes colors according the current joint angle. In addition, a sliding bar's indicator moves according to the angle. The color system for both the bar and text feedbacks are as follows: green when the angle is in a normal angle range, orange the is 20° to the limit recommended and red when is outside that limit. These measurements are arbitrary and can be changed as seen fit. The ranges are setup by default according veterinary data from past research [2, 9]. However, the user can change the expected ranges according to the dog's capabilities. For instance, if a Border Collie dog is more flexible than the average on its breed (the average angles for their ankle range from 50° to 180°), the user can modify that range to fit his dog capabilities as recommended by veterinarians. Then the system is going to adequate the feedback to this new range. Another example is for a dog that is part of a rehabilitation program after surgery that its range of motion may be limited. This feature make our system highly adaptable to different use cases. The application stores exercise data such as flexion angle, extension angle, and range-of-motion angle, to evaluate the progress over time. When the exercise session ends, the app provides a summary of the session such as maximum and minimum angle reached. The stored data shows the session's progress as line graphs. The user can see maximum and minimum angles reached during each session and compare this measurements with the average angles and sort the sessions by time (See Fig. 4).

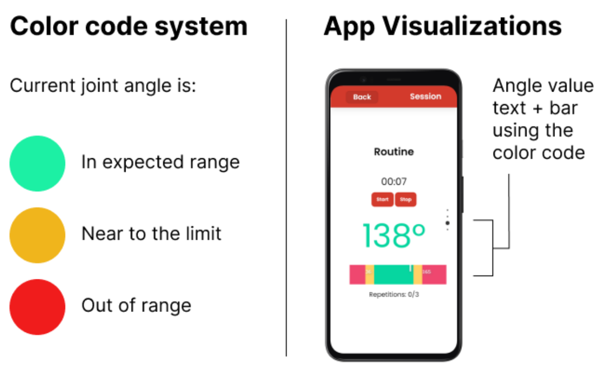


Figure 3: Types of feedback provided by WOOFlex

4 TECHNICAL EVALUATION

The goal of our evaluation is to compare the accuracy of WOOFlex against the Universal Plastic Goniometer (UG). To evaluate goniometers we follow similar exercise protocols to what veterinarians would traditionally do [2] with physically rehabilitating dogs. For these test, we measured the tarsus, stifle, carpus, and elbow joint of 1 young Border Collie dog. We lay the dog down on his side and then place the wearable using the Velcro straps on each side of the joint we want to measure. We then connect the device to the application, select the appropriate settings such as breed and joint to measure, and start a session. First, warm up the joint and

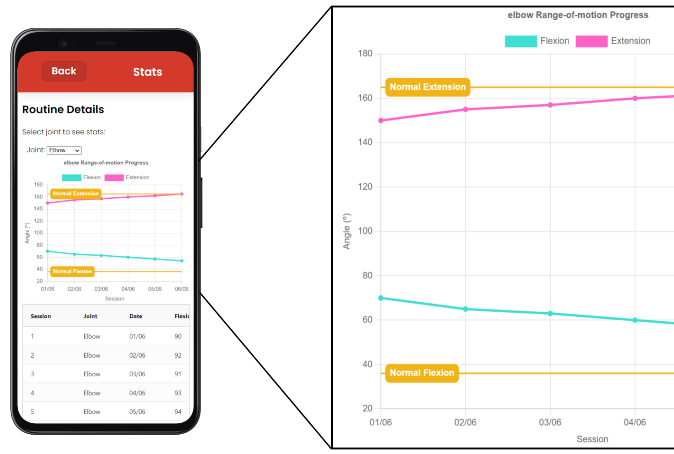
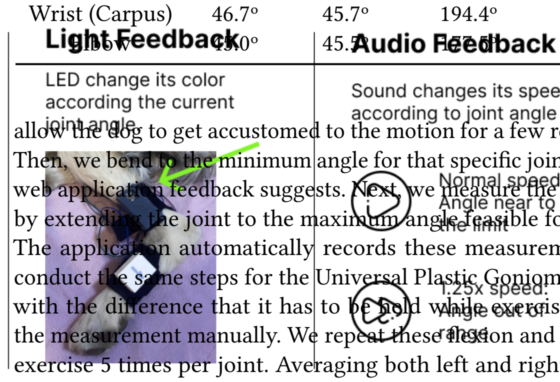


Figure 4: App statistics

Table 1: Average flexion angles obtained with UG and WOOFlex

	Flexion		Extension	
	UG	WOOFlex	UG	WOOFlex
Ankle (Tarsus)	45.7°	44.7°	176.7°	177.6°
Knee (Stifle)	45.4°	44.4°	177.8°	178.9°
Wrist (Carpus)	46.7°	45.7°	194.4°	200.4°
Elbow	45.0°	45.5°	177.5°	177.9°



allow the dog to get accustomed to the motion for a few repetitions. Then, we bend to the minimum angle for that specific joint, and our web application feedback suggests. Next, we measure the extension by extending the joint to the maximum angle feasible for the dog. The application automatically records these measurements. We conduct the same steps for the Universal Plastic Goniometer (UG), with the difference that it has to be held while exercising and a the measurement manually. We repeat these flexion and extension exercise 5 times per joint. Averaging both left and right sides, as done in previous studies [2], we get a total of 10 trials per joint each for UG and WOOFlex. Our prototype's results at Table 1 and Table 2 shows consistency with both the UG and past results used for reference [2].

In order to analyze how similar our device measures compared to the universal goniometer, we performed two two-way equivalence tests on the flexion and extension angles we measured. We tested the same dog's left ankle for a total of 92 times. 46 times with the UG measuring flexion, 46 times with the UG for extension. 46 for Wooflex with flexion, 46 for extension. For flexion, with $\alpha = 0.05$, we have a maximum p of 0.0427 when the bounds of difference are set at |1.5| degrees. For extension, with $\alpha = 0.05$, we have a maximum p of 0.0317 when the bounds of difference are set at |1.5| degrees. The results suggest that the similarity, or equivalence, of the universal goniometer compared to our device is significant within the ranges of 1.5 degrees higher or lower. The exact results can be seen in Table 2.

Table 2: Results of Accuracy test on Ankle

	Average	α	lower t ratio	upper t ratio	max p value
Flexion	45.815	0.05	2.132	-1.739	0.0427
Extention	177.630	0.05	1.879	-4.152	0.0317

5 DISCUSSION AND FUTURE WORKS

When comparing WOOFlex with a UG, our prototype demonstrated its near equivalence in effectiveness. We will conduct our next tests with more dog owning users to see if our proposed benefits may be supported. WOOFlex is more secured on the dog than a UG.

The idea of tracking and provide feedback on a dog's flexibility is one of our notable contributions. Our application shows an implementation of this tracking and feedback. Our main focus is the feedback and canine applicable form factor that we provide in addition to the electronic goniometer we created. As of this paper, we have only evaluated the feasibility of our device, but future work includes implementing more features that make the device applicable to the task. We incorporated veterinary data from past research to provide a guidance on the average range of motion for each joint and specific breeds [9] and also the feature to customize the range of motion according to the dog particular case. The application shows a moving tick on a color coded bar to show stretch level instead of showing the angles alone. The intention is to help the owner or caregiver to not exceed the recommended joint angle. In addition, we use sounds and speech alerts to help warn the human if a stretch is becoming intense. Future work includes adding muscle tension sensors to determine the intensity of stretch, adding elasticity to our orthopedic braces for a more comfortable fit, and reduce the 3D printed container size to be less bulky. We will conduct future user studies with a wider range of dogs to evaluate the WOOFlex performance. We will evaluate the system with a variety of stakeholders, including veterinarians and pet owners to evaluate our interface and feedback system. Future studies will also examine how our method compare to other poses or doing the exercise without any goniometers.

6 CONCLUSIONS

We present WOOFlex, a wearable device that assesses and aids in canine flexibility exercises through worn IMUs that sense the range of motion and an app that provides different kinds of feedback. This tool is intended to assist alongside canine physical rehabilitation treatments, as well as competitive training and general dog care. Our prototype was tested to be within |1.5| degrees of difference from the universal goniometer. Our aim is that this device will promote dog flexibility exercises as a common habit and allow pet caregivers to perform their exercises adequately.

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