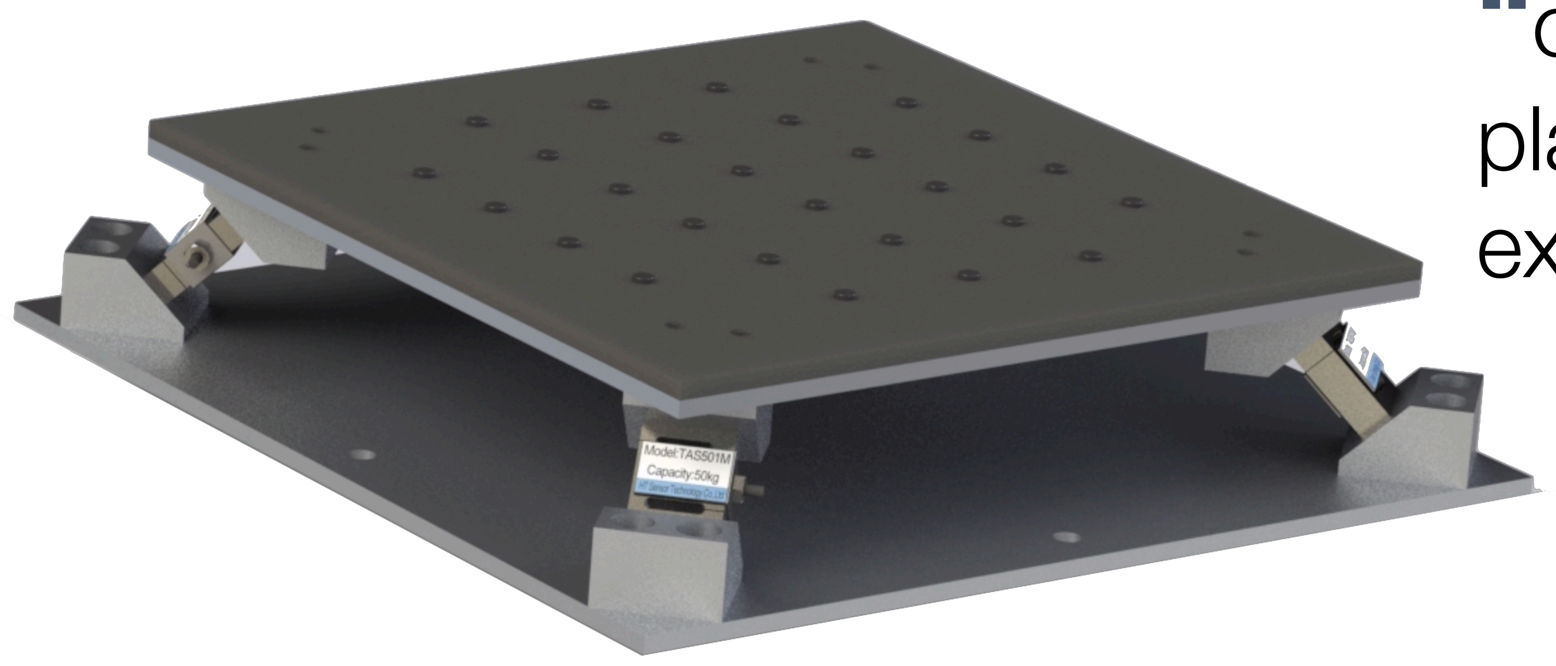
Low-cost Three Axis Force Plate

Using neural networks and other machine learning techniques

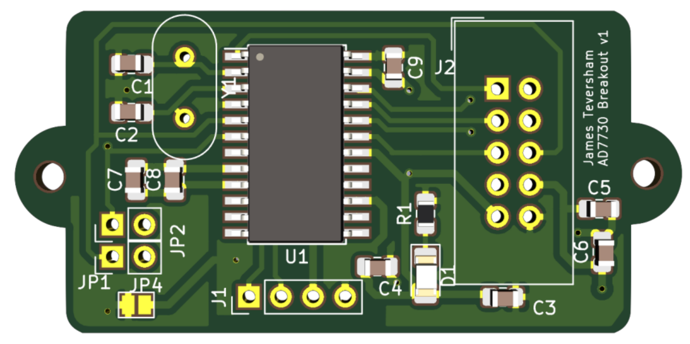
Overview

This project presents the novel design of a low-cost force plate capable of accurately estimating three axis ground reaction forces (GRFs).

Mechanical design | Embedded software | Electronic hardware | Machine learning



"commercial force plates typically cost in excess of 30 000 USD



PCB for AD7730 amplifier/ADC

Motivation

Force plates are used extensively in commercial and academic fields. Intricate force profiles are used in analysis of athletic performance and rehabilitation of sporting injuries. Force plate gait analysis has allowed for remarkably accurate diagnosis of degenerative motor-related disorders such as Parkinson's Disease and Multiple Sclerosis.

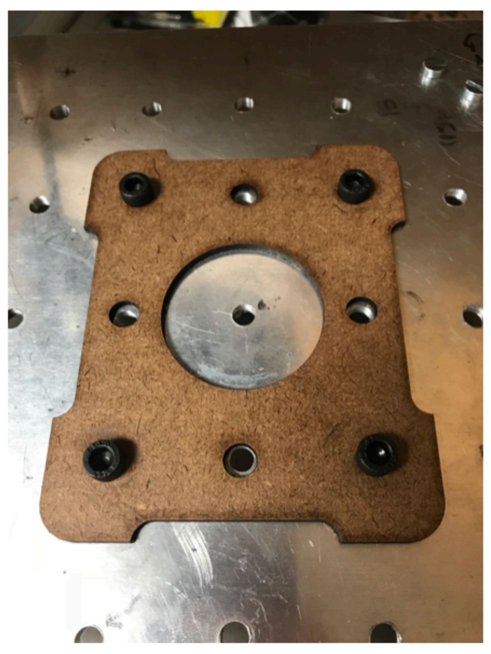
This technology also offers a non-invasive means of studying GRF interactions of animals (such as the cheetah) during rapid and complex manoeuvres. This data is indispensable for mechanical design and control systems in bio-inspired robots.

Cost is the biggest limitation of this technology. Commercial force plates typically cost in excess of **30 000 USD**, rendering them impractical for may small scale academic and business applications.

Methodology & Implementation

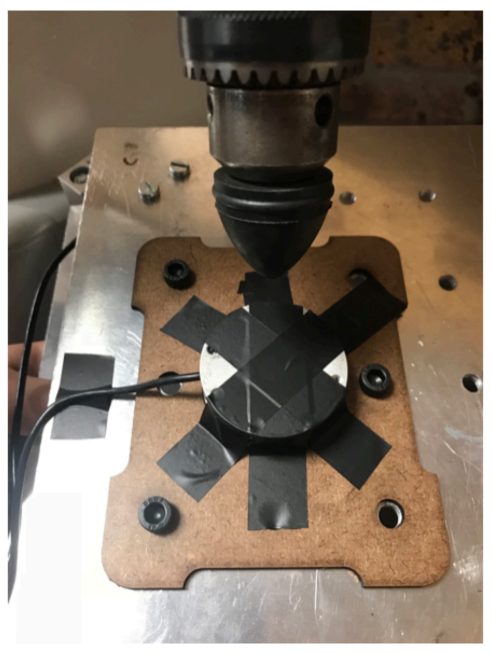
All forces tested on the plate were applied through an OptoForce three axis force sensor which provided the 'truth data' of GRF components to be used in training of regression models. A drill press fitted with a stiff rubber foot was first used to provide isolated single and two-axis loads before unconstrained three axis tests were conducted.

Natural gait experiments were performed for walking and running. A human subject was requested to walk on the plate (along its y-axis) but was instructed to allow mediolateral (x-axis) sway during push-off to truly test the system's ability to estimate three axis GRF components simultaneously.



Mounting brace to prevent slipping of OptoForce sensor

OptoForce sensor mounted on plate



Two axis test with drill press

The novel mechanical design used only **four single axis load cells** mounted at predefined angles between two plates. A machine learning approach was chosen to avoid the significant analytic challenge of solving the non-linearities arising from the mechanical design.

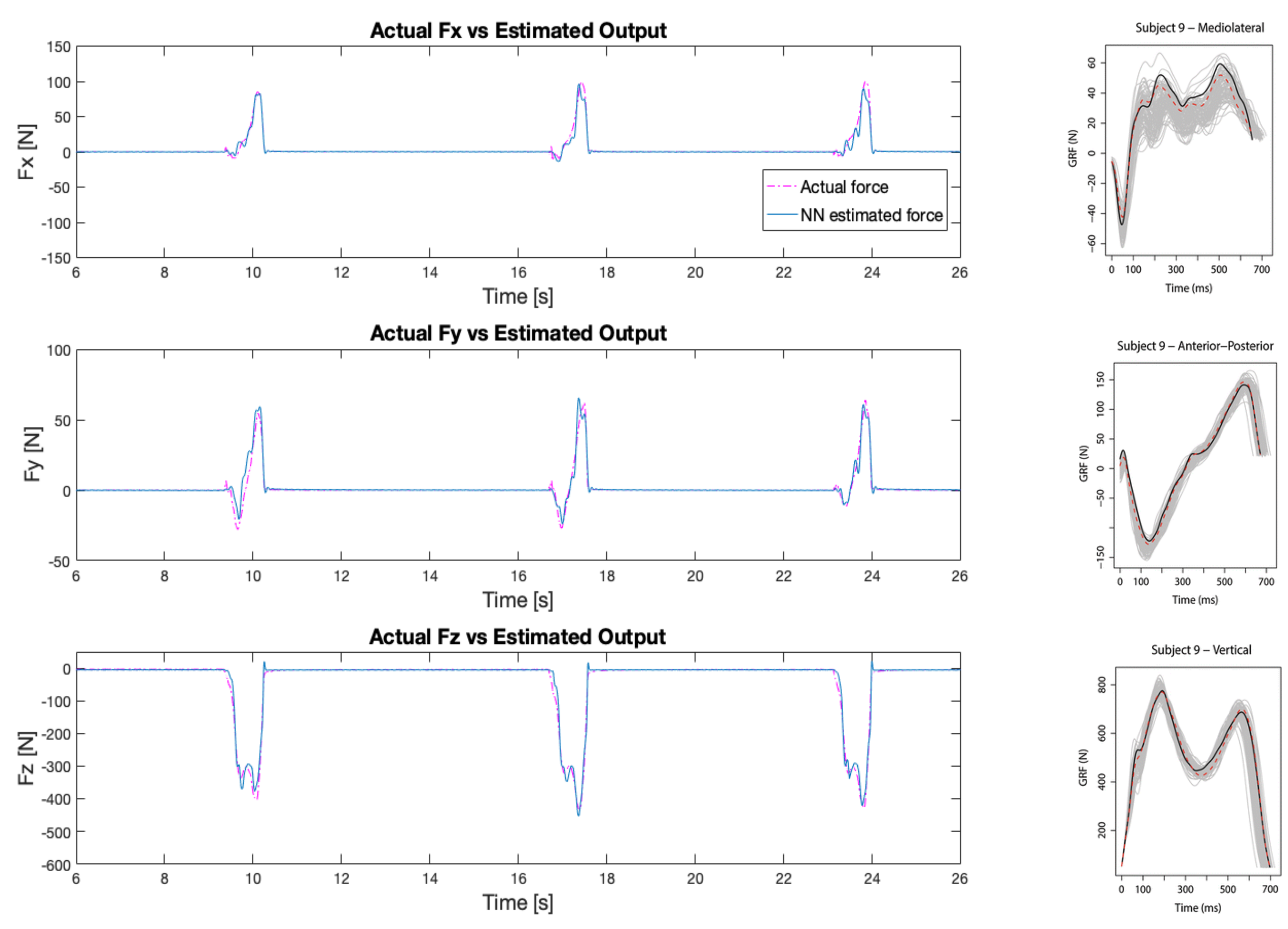
DAQ System

The electronics and embedded software comprising a comprehensive data acquisition (DAQ) system capable of logging to an SD card at **1kHz** were developed from scratch. A discrete array of 26 momentary switches was used to determine the position of the applied force on the plate.

Results

Various machine learning regression models were implemented using MATLAB. These included linear regression, SVM, neural network and ELM (extreme learning machine) implementations. The system was tested to work reliably with forces up to **600N** in the vertical axis and **150N** in the lateral axes. Testing apparatus limited larger force experiments.

The graphs below show the impulsive GRF profiles obtained in natural gait experiments (during walking). Optimal performance was achieved by a feed-forward neural network with 10 hidden neurons and trained using Levenberg-Marquardt backpropagation. GRF profiles from a published study are shown to the right of the experimental results for each GRF component. RMS errors for estimated GRFs, expressed as % full scale force, were **1.714%, 1.544%** and **0.575%** for the x-, y- and z-axis components respectively.

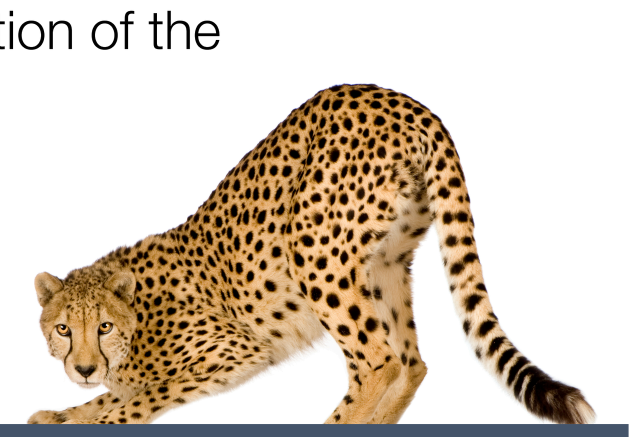


Profiles extracted from a study of human gait

Estimated and actual GRF curves (experimental)

Conclusions and Future Work

The result of this project was an extremely promising proof-of-concept system that was produced at a cost of approximately 50 times less than typical commercial force plates. Future work should explore the use of a continuous mechanism of detecting the position of the applied force. Further testing on humans and field experiments conducted on the cheetah will be the next major test for this system.



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