Small force sensor to measure the three components of the ground reaction forces in mice

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1 Introduction

Measuring the ground reaction forces (GRFs) helps in determining the role of each limb for support and propulsion, in predicting muscle activities, and in investigating the strain conditions experienced by bones. Measuring the GRFs in mice models is therefore a cornerstone for understanding the rodent musculoskeletal and neuromotor systems. Available force plates are too big to measure the forces for each paw, particularly for successive steps - with the main limitation being the large size of the underlying force sensors. The goal of our study was therefore to develop small force sensors to measure the 3D ground reaction forces for successive steps during mouse gait.

2 Methods

Our force plate design uses a mechanical beam structure similar to the force plate used in a lizard study [1]: two perpendicular beams that contain slots in different directions (Figure 1). This mechanical beam structure allows the decoupling of the three components of the force: the vertical direction F_z, the fore-aft direction F_x and the mediolateral direction F_y, (Figure 2). To have a flexible structure, the perpendicular beams were made of polycarbonate (E= 2.3 GPa, υ= 0.37). A glass plate of 100mm × 17mm × 2mm was fixed on top of four of these mechanical beam structures. In order to measure the strain, two strain gauges (KFGS-5-120-C1-23 Kyowa) were fixed on each wall of each slot and were connected in a half-bridge configuration. Strain modules (EDX-14, Kyowa) and one control unit (EDX-10B, Kyowa) measured these half-bridge circuits and transferred the data for visualisation to a PC using the DC100 software.

To calibrate the force plate, we used weights from 1mN to 200mN. The weights were placed on the top plate to measure forces in the vertical direction, while and a pulley system applied forces in the horizontal directions.

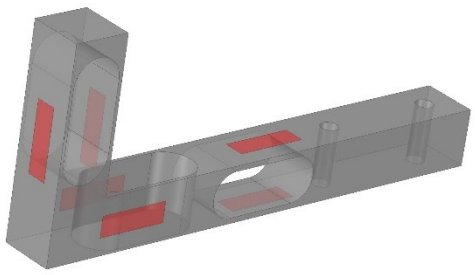

Figure 1: The mechanical beam structure of the 3D sensor with the placements of the strain gauges as red rectangles.

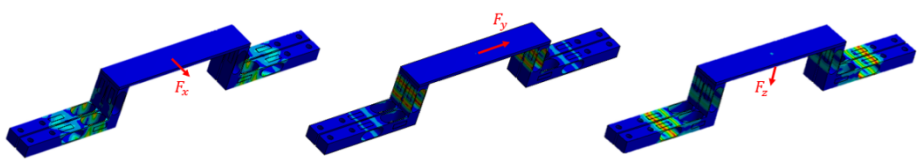

Figure 2: Simulation of strain for uniaxial forces applied in the three different directions F_x, F_y and F_z. The dark blue stands for no strain and the red for the highest strain.

3 Results and discussion

The force plate (Figure 3) was able to measure forces down to 2mN in the vertical direction and 1mN in the horizontal directions. The sensitivity was about 1700µm/m for the vertical direction and 600µm/m in both horizontal directions (Figure 4). The crosstalk between the channels was 0.5% in the vertical direction and 2% in the two horizontal directions. For a glass plate of 100mm × 17mm × 2mm, a finite element analysis estimated the resonance frequency as 96Hz, which could be increased by using a larger plate while keeping the same height. We believe that the resolution can be further improved by increasing the supply voltage of the bridge circuits and reducing noise sources.

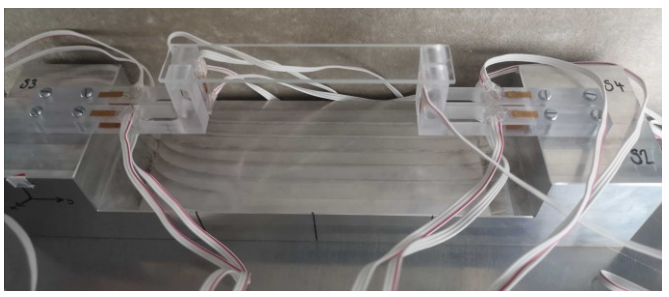

Figure 3: A prototype of the miniature force plate. The top glass plate is fixed on four mechanical beam structures to which strain gauges are attached

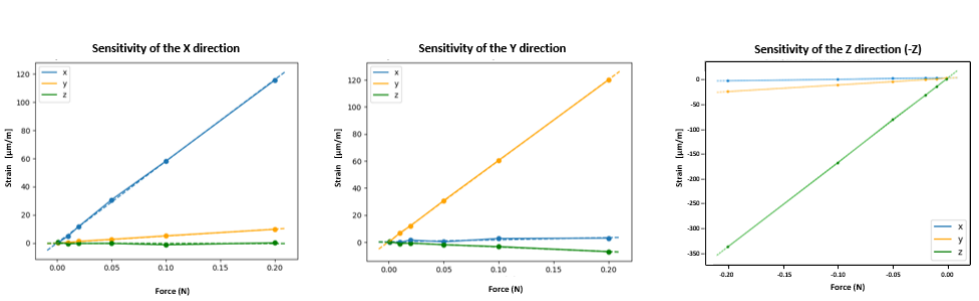

Figure 4: The force plate sensitivity and crosstalk for uniaxial forces applied in the X direction (left) , Y direction (middle) or Z direction (right).

4 Conclusion

In this project, we created a miniature force plate sensitive enough to measure the three components of the GRFs in mice.

After arranging these force plates in a runway, the GRFs per paw for successive steps can be determined. Our force plate offers perspectives not only for applications in mouse gait analysis, but also to ultimately translate results from mice to humans.

5 References

1. Katz, S.L. and J.M. Gosline, Ontogenic Scaling of Jump Performance in the African Desert Locust (Schistocerca-Gregaria). Journal 571 of Experimental Biology, 1993. 177: p. 81-111