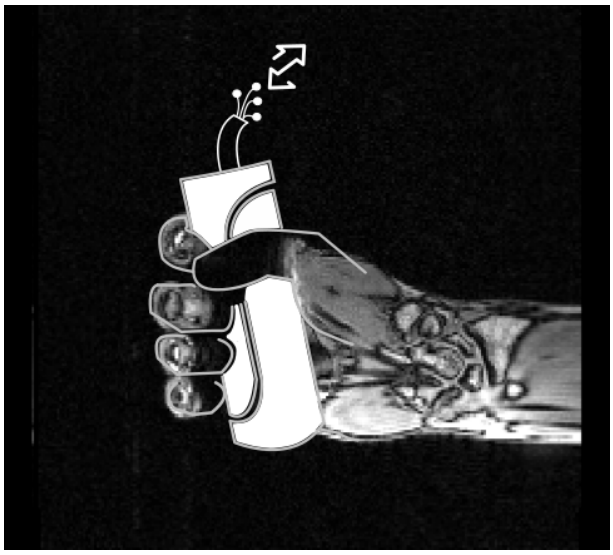

Open Grip Force Instruction

Version 0.1.0

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Contents

1 Introduction

This document provides step-by-step instructions to build the MRI-compatible Open Grip Force Sensor based on the Open ForceSense MR developed by Francesco Santini,[1] distributed under the GNU General Programming License (GPL) V 3.0.

The casing was designed using FreeCAD[2] (version 0.21.2) and manufactured with a commercial 3D printer (model A1 from Bambu Lab, Shenzhen, China). The enclosure accommodates two beam load cells (each rated for 50 kg/490 N) configured in parallel to function as a single 980 N load cell. These load cells connect to an HX711 amplifier and an analogue-to-digital converter (ADC), delivering measurements with a temporal resolution of up to 10 ms. Force data from the ADC is processed by an Arduino Uno Arduino Uno microcontroller[3], which continuously collects and transmits the data via USB to a connected PC.

A Python program with a graphical user interface (available here[4], with Python version 3.13.0) receives the force data, displaying it in real time while saving the results as text files in Newtons or Kilograms.

To ensure signal integrity, the sensor's electrical connections to the HX711 board pass through a custom-designed low-pass filter, incorporating 100 μH inductors. This filter protects the Arduino microcontroller from gradient- and RF-induced voltages while reducing electromagnetic interference in MRI imaging.

Follow the instructions carefully to assemble a functional and noise-robust grip force measurement system. Updates or modifications will be posted GitHub[5].

2 Material List

Additional material: Soldering iron, cable ties, 3D printer.

[1] https://github.com/fsantini/OpenForceMR
[2] https://www.freecad.org/
[3] https://store.arduino.cc/products/arduino-uno-rev3
[4] https://github.com/fsantini/OpenForceMR/tree/master/GUI
[5] https://github.com/BAMMri/Open-Grip-Force

2.1 Grip Force Sensor

	Item	Quantity	Approx. Cost (CHF)	Links & Notes
	Aluminium Beam Load Cells (50kg)	2	7	
	HX711 Amplifier	1	1	
	Arduino Uno	1	4	
	3D Grip Casing	1	2	approx. 50g of PETG filament
	Brass Screws	8	4	4 each: M5x20 and M4x20
	Ethernet Cable	2	15	length depends on your setup, here: one 20 m and one 50 cm cable
	**Miscellaneous Components (e.g., wires, solder)**	collection	5	
	Solder			
	Wires			
	Breadboard			
	Cooper braid			
	Shrink tubing set			
	Total Approx. Cost		60	

2.2 Filter

Item	Quantity	Approx. Cost (CHF)	Links & Notes
Inductors	7	0.50	
3D Casing	1	1	approx. 25g of PETG filament
Connectors	4	?	depents on needed connection here: NEMS and force measure
Springs	4	?	
Miscellaneous Components (e.g., wires, solder)	collection	5	
Solder			
Wires			
Shrink tubing set			
Total Approx. Cost		10	

3 Grip Force Sensor Assembly

1. Download and print the respective 3D model[6] for the grip force sensor casing. We use a PETG filament and the standard bamboo lab 0.08 mm layer height, High Quality settings with modified infill density of 50%, a Honeycomb pattern and Tree Support.
2. insert the two load cells with opposing force transduction into the casing and secure with brass screws. As schematic indicated in assembly **??**. The cable attachment points should face inwards.

[6] https://github.com/BAMMri/Open-Grip-Force

3. Feed the cables through the upper circular hole of the casing. Make sure the cables do not interfere with the free end of the loadcells or the slit.
4. Cut all the cables coming out of the sensor casing at the same length and solder the cables of the same colour together. This ensures a parallel connection of the Wheatstone bridges that can therefore act as a single sensor.

4 Arduino Hardware and Software Set-up

Firstly we will prepare the approx 20 m ethernet cable which connects the force sensor to the arduino. Therefore cut the connector from **one** end of the ethernet patch cable and expose the internal wires. We now attach the force sensor wire to the ethernet cable with the soldering iron. Before soldering, always remember to pull over the shrink tubing and copper braid! Pull an approximately 15 cm chunk of copper braid and respective shrink tubing over the ethernet cable. Place a piece of shrink tubing over each wire you are about to connect. Then connect **Sensor to Ethernet Cable** according to Figure 3:

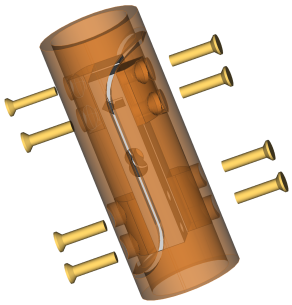

Figure 1: Schematic of the grip force sensor assembly.

- Red (Incentive +) $\rightarrow$ Ethernet Pin 1
- Black (Incentive -) $\rightarrow$ Ethernet Pin 2
- White (Signal -) $\rightarrow$ Ethernet Pin 6
- Green (Signal +) $\rightarrow$ Ethernet Pin 3
- Yellow (Shield wire) $\rightarrow$ Ethernet Shield

Cover the connections with shrink tubing and glide the copper braid over them. Secure the copper braid in place with cable ties.

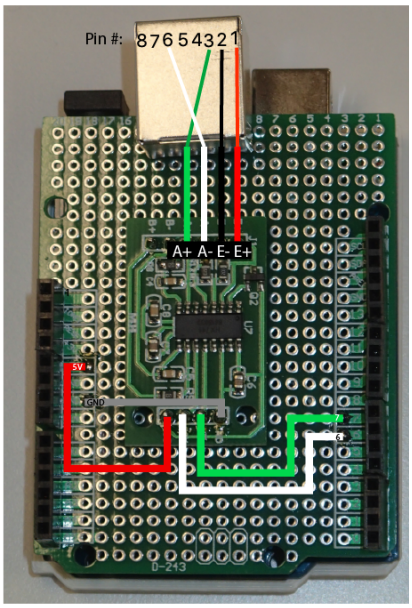

Figure 2: Wired Arduino Shield

4.1 Solely Force Measure

Next step is to wire the Arduino and build a circuit board shield as depicted in Figure 2 and 3. In case you don't know how to build a shield, here is a nice tutorial[7]. You are not obligated to build a shield. A classic pegboard approach is equally good.

Load Cell Amp to Ethernet Cable

- RED/ E+ → Ethernet Pin 1
- Black/ E- → Ethernet Pin 2
- White/ A- → Ethernet Pin 6
- Green/ A+ → Ethernet Pin 3
- Yellow/ SD → Cable Shielding

Load Cell Amp to Arduino

[7] https://youtu.be/0Hw6-1Gk8eI?si=Ltapn_s1rKC4tmFX

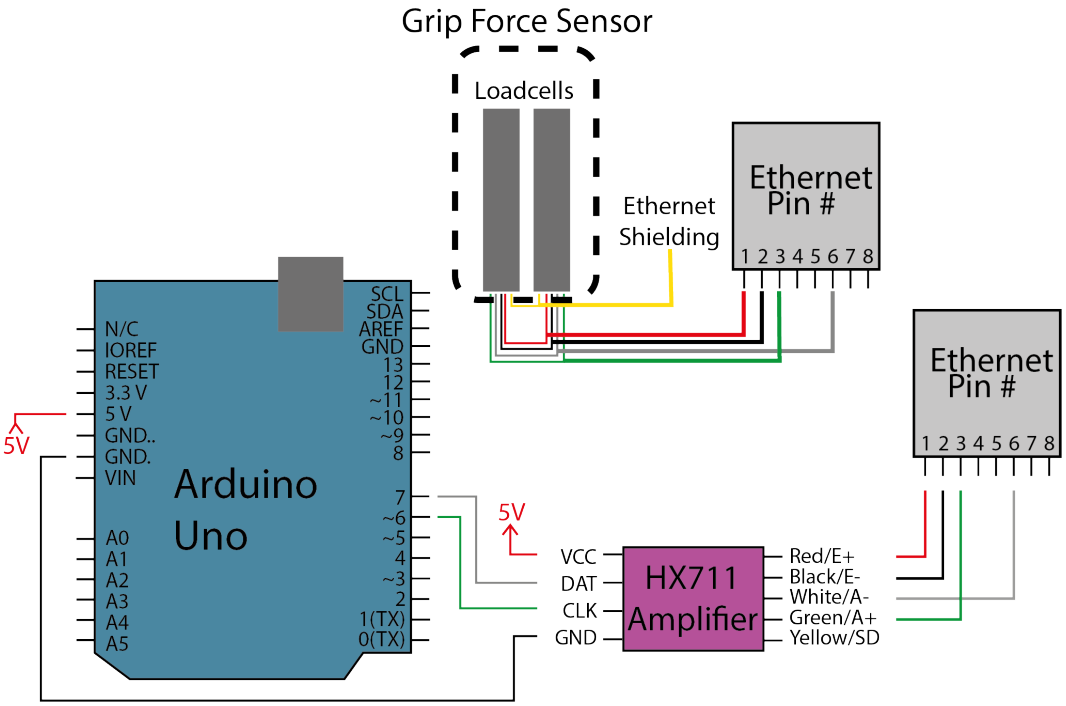

Figure 3: Schematic sketch of the Grip Force Sensor

- VCC (RED) → +5V
- DAT (WHITE) → PIN 7
- CLK (GREEN) → PIN 6
- GND (BLACK) → GND

4.2 Force Measure and NMES

To extend the grip force measurement with synchronized NMES you need a different arduino shield. Things tend to get a bit more complicated here, but don't worry if you are not an expert you can do it too. Aim is to produce a arduino shield as depicted in Figure

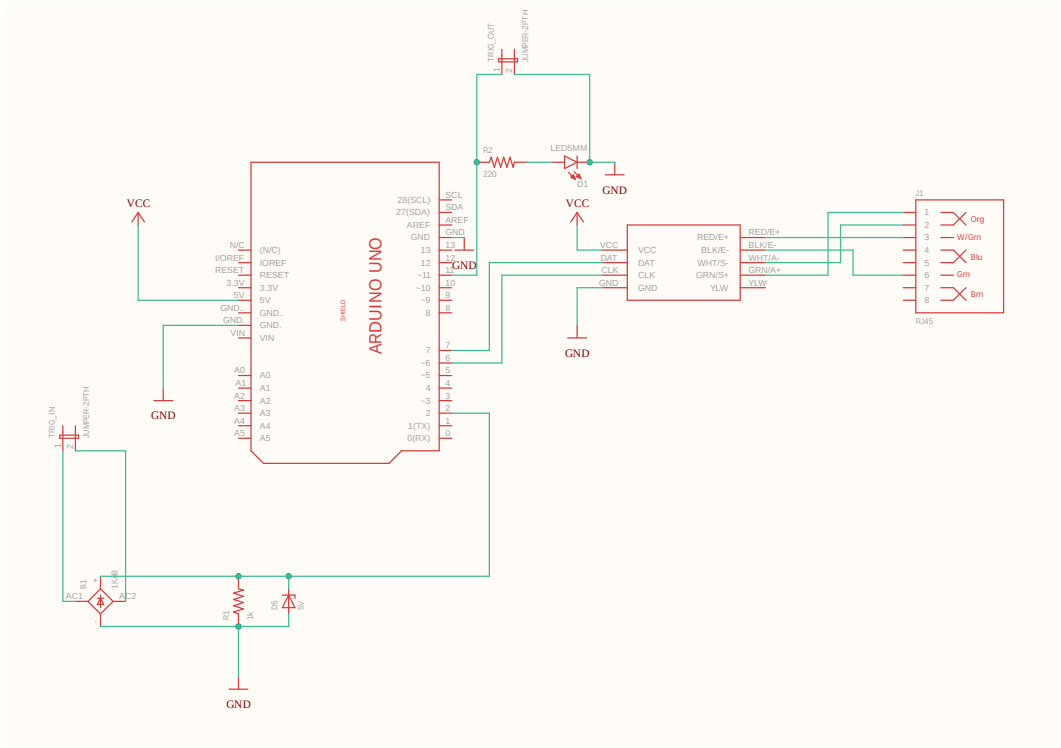

Figure 4: Arduino shield sketch for simultaneous NMES, scanner triggering, and grip force measurement. Source: GitHub EMS Trigger Force.

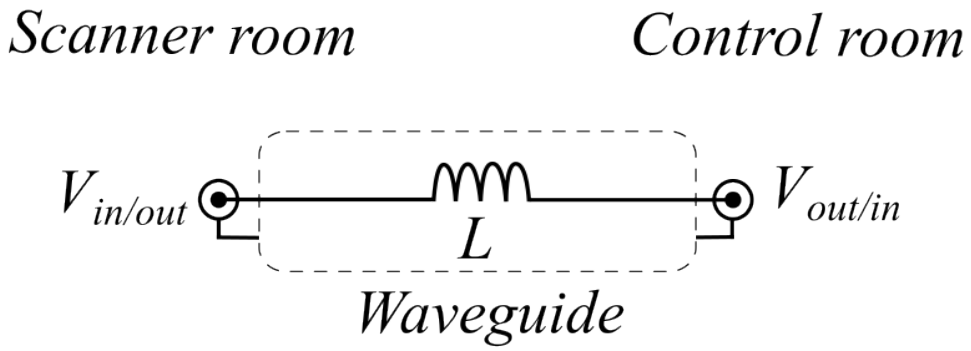

Figure 5: Schematic sketch of each cable of the low pass filter installed in the waveguide

4.3 Software

Next step is to upload the scale sketch to the Arduino board by using the Arduino IDE Software[8] and download the GUI to your PC.

4.4 Scale Factor Calibration

Eventually, the load cells need to be calibrated to correlate output voltage with the measured force defined by the scale factor. The current NMES Arduino sketch enables the local storage of up to 10 scale factors. So even upon power disconnection, the scale factors will be stored within the Arduino Eprom, allowing the user to connect multiple force sensors with varying scale factors. To calibrate the scale a known weight is placed on the sensor and the scale factor (ScaleFKT) can be calculated as:

$$ScaleFKT_{new} = \frac{ScaleFKT_{old} \cdot Weight_{measured}}{Weight_{reference}} \quad (1)$$

5 Filter Assembly

6 Final System Assembly

Figure 6 depicts a schematic sketch of the final assembly of all components. One channel of the EMS device (placed in the control room) is connected

[8] https://www.arduino.cc/en/software

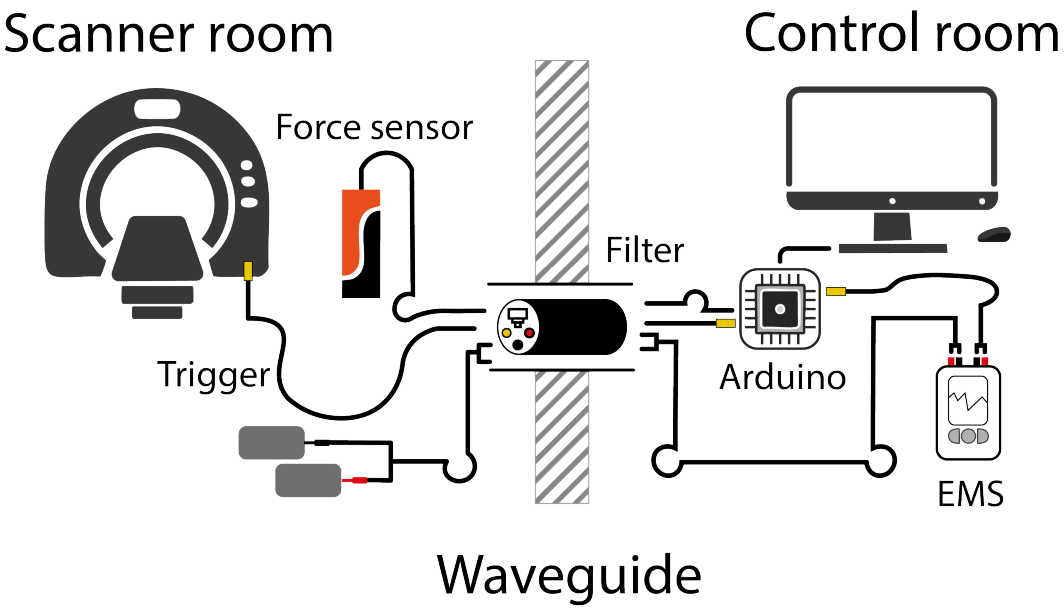

Figure 6: Schmatic sketch of the final assembly of all components.

directly to the Arduino, which generates a 5V trigger signal for the MRI scanner upon stimulation and is fed through the waveguide with the filter into the scanner room. The other channel of the EMS device is fed into the scanner room via the filter. Coaxial cables are connected to the EMS electrodes inside the scanner room. The force sensor sends the signal via the Ethernet cable through the waveguide with filter directly to the Arduino outside of the scanner room. The Arduino is hooked up to a pc where the Python GUI interacts with Arduino to display force values and store the data upon command into a text file.