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Project 2

Snow Profiler - Proof of Concept

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degree program

MASTER MECHATRONICS AND SMART TECHNOLOGIES

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1 Proof of concept of mechanical design

1.1 Probe stability

The mechanical design of the probe matches all outer force influences. The safety mechanism is working (when cables are not twisted) and protects the force sensor from too high forces (e.g. hitting a stone or the ground). The structure of the top housing proves to be very stable despite the 3D print and the Inlets for the electronic components are stable enough to resist the forces when mounted into the probe.

Due to cost reasons (milling of stainless steel) the probe is manufactured out of normal steel. For the usage in snow it is recommended to manufacture the parts, as planned, out of the ordered stainless steel.

1.2 Sensor protection

The safety mechanism prevents the force sensor from a defect at several cases where the probe hit the metal during the testing. The only porblem occuring is the twisting of the cables, what can easily be prevented by adding a groove to the front part of the safety mechanism. Further the mounting of the MCU in the top housing proved to work. No damping must be added due to the acceleration data.

1.3 Flight behavior

Throughout all the tests the probe flew straight and did not fall to any side (no misallignment of the y-axis). This has been approved by dropping it freely from about 4 meters without a rope connected to the top housing. With the winch at the drone as well as at the testing tower, the probe is likely to fall straight without a misallignment out of the y-axis.

2 Theoretical calculation of drop height

To get an idea about the desired height for dropping the probe into the slope with a penetration depth of 1 meter, a rough calculation in MatLab is carried out. In figure 1 three possible snow profiles with different layers are defined, with snow profile 2 being the hardest one to penetrate. Snow profile 1 is a sample of a realistic snow profile measured by Hagenmuller [1].

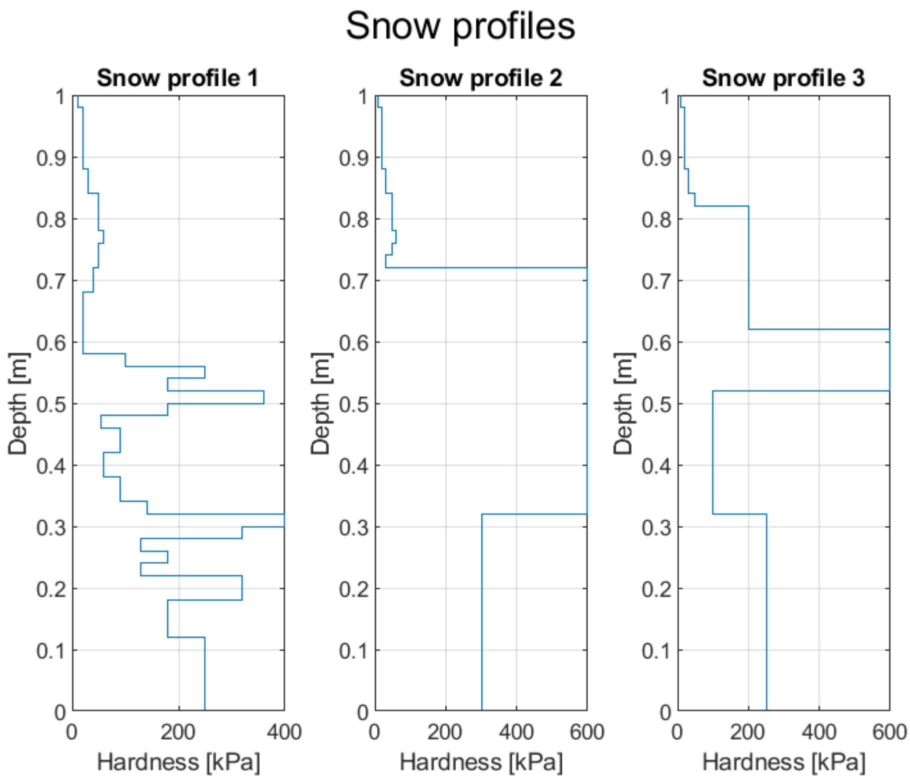

Figure 1: Snow profiles for drop height calculation

The snow profiles given with the hardness are reformulated by multiplying with the cross section of the probe to get the force over depth. This is afterwards integrated to get the needed energy. The energy is the needed energy of the probe when entering the surface of the slope. With the calculated energy and the weight of the probe, the needed drop height can be calculated.
The theoretical drop heights are depicted in table 1.

Table 1: Drop height for different snow profiles

Snow Profile	Properties	Drop heigth / m
1	Realistic	1.7
2	Hard	4.8
3	Alternating	2.8

3 Layer detection

The layer setup in Table 2 was used to verify if the system is able to acquire valuable information about the composition of a snow profile.

Table 2: Layer setup for measurement in Figure 2

Position	Material	Thickness / mm
1	Styrofoam	50
2	Ply Wood Sheet	4
3	Air	70
4	Styrofoam (dense)	30
5	Styrofoam	15
6	Soft foam white	50
7	Dense foam white	75

Figure 2 shows that the different force magnitudes relate to the density of the different materials listed in Table 2. Each of the seven layers can be identified in this measurement. The individual layer thickness, however, could not be computed due to non valid acceleration data. The reason for this lies in the deceleration of the probe exceding the IMU's limits of 16 g. The used materials replacing the actual snow cause high friction on the probe's outer diameter, thus, the probe decelerates too fast. In real snow, such high friction is not expected to occur.

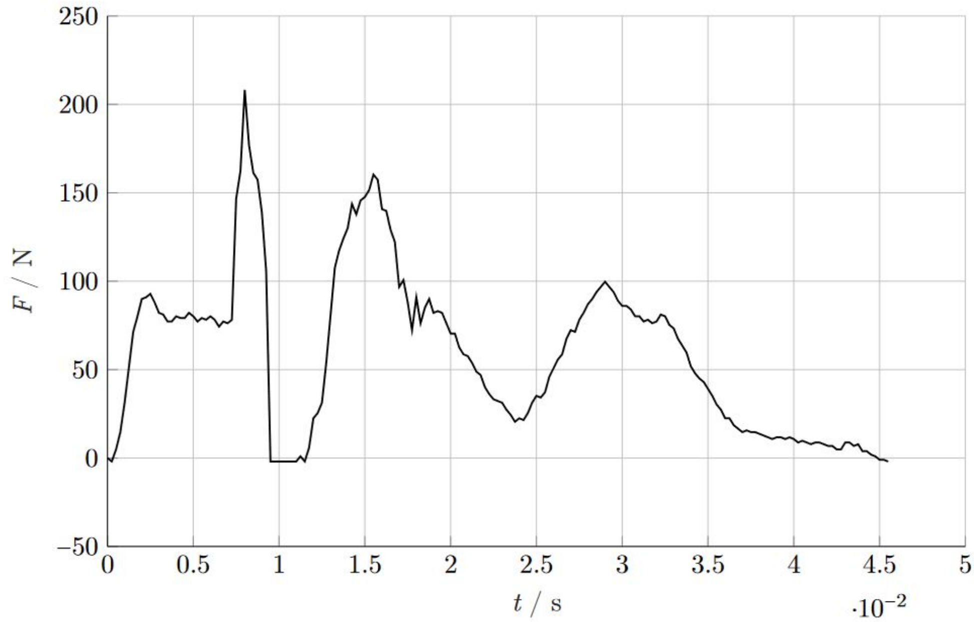

Figure 2: Force measurement on test profile with the layer constellation from Table 2

3.1 Thin weak layer detection

Given the following assumptions, the minimum thickness of detectable weak layers can be calculated:

- The probe does not decelerate in weak layers but even re-accelerates as it would do in free fall (worst case)
- The initial velocity when entering the weak layer is known. For worst case we assume that the entering velocity is same as the velocity afer the free fall (max. velocity)
- We want to have at least two data points within the minimum thickness weak layer
- The force sensor bandwidth is high enough

$$d_{\mathrm{min}} = 2 \cdot \left(\frac{g}{{f_{\mathrm{s}}}^2} + \frac{\sqrt{2 \cdot g \cdot h_{\mathrm{d}}}}{f_{\mathrm{s}}} \right) \tag{1}$$

with:

f_{s} ... smapling frequency

and

h_{d} ... drop height.

Neglecting that the probe re-accelerates within the weak layer, Equation 1 simplifies to Equation 2 and the thinnest detectable weak layer in a worst case scenario calculates to:

$$d_{\mathrm{min}} = \frac{\sqrt{8 \cdot g \cdot h_{\mathrm{d}}}}{f_{\mathrm{s}}} = \frac{\sqrt{8 \cdot 9.81\,\mathrm{m\,s^{-2}} \cdot 8\,\mathrm{m}}}{4000\,\mathrm{Hz}} \approx 6.25\,\mathrm{mm} \tag{2}$$

In order to simulate a weak layer measurement, the layer setup in Table 3 was used.

Table 3: Layer setup for measurement in Figure 3

Position	Material	Thickness / mm
1	Styrofoam	100
2	Ply Wood Sheet	4
3	Soft Styrofoam	10
4	Ply Wood Sheet	4

Figure 3 clearly shows two peaks representing the ply wood sheets. In between of them, the force drops to lower levels that represents the weak layer.

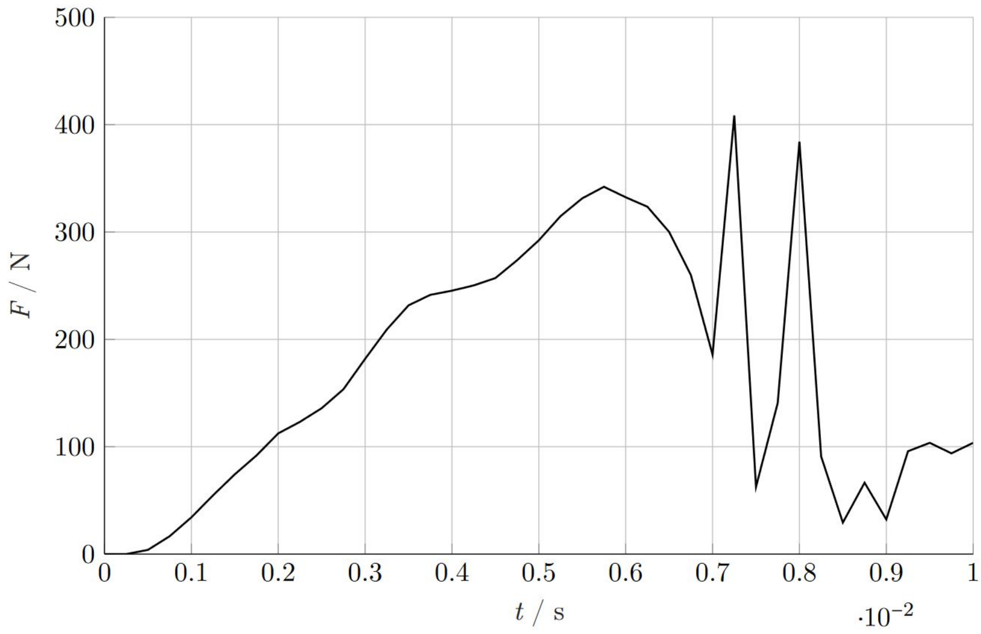

Figure 3: Force measurement on test profile with the layer constellation from Table 3

4 Reasons for discrepancies from testing to MatLab

Due to the high friction as discussed in chapter 3, the probe did not penetrate the materials of the testing device further than 40cm. To validate the penetration depth dependency of the friction, the testing was done with different material combinations, whereas the depth was approximately the same. Despite the adding of wooden layers the probe did penetrate as deep as without the wooden layers.
Furthermore, the materials ordered for testing did not match the properties we defined in the first place to replace real snow. The friction coefficient is too high. The material is to elastic, therefore it absorbs too much energy and the brittleness of the icy layers is not given by the wooden plates.
Another aspect for the penetration depth is the weight. At the current state it is around 2,3 kg and can be increased as demanded by adding weight to the probe. This can be done by led inserts that connect directly to the back mounting ring.

5 Conclusion

The design developed in the first semester is approved with very small changes at the overall snow profiler. The first produced prototype comes with all functionalities (despite the anti twisting groove and the glued screwing of the force sensor) necessary to build a real testing probe for the use in the field.
All Sensors despite the capacitve and the infrared sensor are included and in use at the current prototype. This includes a video of the snow layers, a force measurement at the tip and acceleration data gatherd by the IMU at the top housing.

To validate the concept and the penetration depth in more detail, the snow profiler must be tested in the real working environment. Therefore it is recommended to manufacture the probe fully out of stainless steel to be able to test it in the slope. Furthermore the capacitve and the infrared sensor must be added at the designed PCB for further and more precise testing data.

References

[1] P. Hagenmuller, "Inter-comparison of snow penetrometers (ramsonde, Avatech SP2 and SnowMicroPen) in the framework of avalanche forecasting," 2016, Conference paper.

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