Ice Detection Sensor

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***Abstract*—Coupled with the danger of of black ice on roads, this report covers the work of designing an ice detection sensor as a part of II2302 Sensor Based Systems. Three IR LEDs shine light on top of a surface and by measuring the power of the back-scattered light, it is theoretically possible to differentiate between water, ice and dry surface. In practice, the sensor needs to be in controlled environments with multiple factors affecting the performance of the sensor. The project group constructed such a sensor and is confident that the sensor is able to detect different surfaces, although no attempt was made to characterize the surface material.**

I. Introduction

Each winter, ice becomes a major cause of cyclist accidents. Slipping on the ice while riding on a bike can lead to injuries by falling on the ground, or by causing a collision with other road users. The system we tried to develop during this project is a sensor capable of detecting ice, and differentiating it with water as well as a dry surface. We wanted to develop this sensor as an accessory that would be mounted on a bike during winter. It would detect the presence of ice on the road ahead of the rider and alert him so that he can slow down or avoid the ice.

The specifications expected at the beginning of the project were:

- Accuracy of the detection: 95%
- Distance of the detection: $50cm$
- Speed of the detection: $100ms$
- Power consumption: $100mW$

The design features three IR LEDs, with wavelengths 1300 nm, 1450 nm and 1550 nm, with an InGaAs photodiode receiving the IR light reflected of the surface [1]. Each LED is pulsed sequentially, where the system samples the back-scattered light.

II. System Architecture

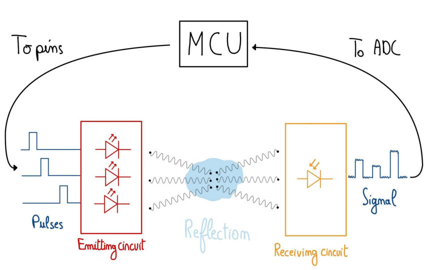

Fig. 1. Top level diagram of system function

The initial decision was that the electronics would be split up into two separate circuits, one for controlling the emitted IR power, and one for sensing and filtering the photodiode output.

The system is controlled by a STM32F4ZI-NUCLEO development board. The custom circuitry was milled on a separate PCB, where we exposed a 7 pin interface to the microcontroller.

A. Emitting Circuit

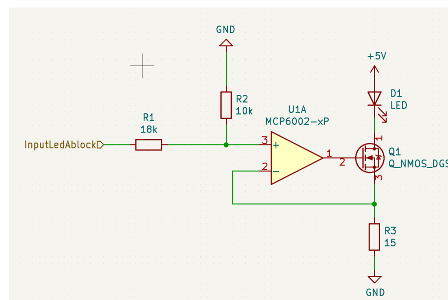

Fig. 2. Diagram of emitting circuit

The topology used for the emitting circuit is given in figure 2. The cost of each IR LED was above 100 SEK, so in order to ensure we don't damage the LEDs, we opted to construct a stable current sink for each LED.

The opamp (MCP6002) is configured such that the voltage across the resistor is equal to the control signal coming from the microcontroller (divided by three). Due to ohm's law, the current through D1 is then controlled by the input signal to the opamp. The GPIO pins of the microcontroller is 3.3 V, so the current through R3 is approximately 67 mA, but was in practice closer to 75 mA.

Six of these circuits were installed on the PCB, such that we could install two of each LED to increase power.

The emitting circuit has the highest power consumption. The momentary power consumption is in practice 375 mW. However, by decreasing the pulse-width, the average power consumption may be lowered below the required 100 mW.

B. Sensing Circuit

The sensing circuit consist of two cascaded opamp stages. The first stage is configured as a transconductance amplifier, where it converts the sensed current through the photodiode into a voltage. The second stage is configured as a non-inverting amplifier and is intended to increase the total gain of the circuit. The sensing circuit topology can be found in figure 3.

The resistor values were decided experimentally as to achieve sufficient gain, such that the reflections were clearly

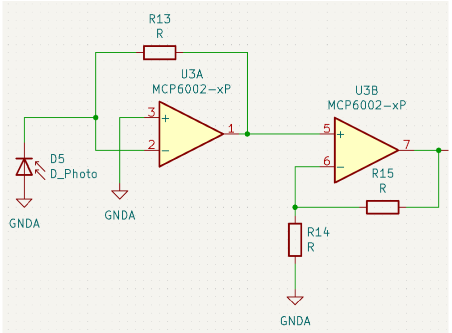

Fig. 3. Diagram of sensing circuit

readable from a 3 cm distance. Unfortunately, we did not record the final values.

DC-offset proved to be a problem when we tested the circuit. We already noticed that this would be a problem when prototyping on breadboards. The initial solution would be to add DC-blocking capacitors between each stage and use multiple non-inverting amplifiers in cascade, each with a lower gain setting. This worked relatively good when protyping, but the capacitors ruined the received waveform. Due to this, we had to omit the capacitors and only use the first stage with higher gain. DC-offset was slightly decreased by adding a 13 $k\Omega$ resistor between the inverting and non-inverting inputs of the non-inverting amplifier.

We added optional components in the design such that we could solder a RC filter. Unfortunately, we forgot to solder these components.

C. Software

The software was developed in C using the STM32 HAL libraries [2]. The microcontroller would turn on each LED sequentially with a period of 200 ms, where the 12-bit ADC available on the microcontroller sampled 2000 data conversions while each LED was turned on. The captured sample would be temporarily stored on the microcontroller, eventually being sent to a computer using the serial connection available through the ST-Link.

D. PCB

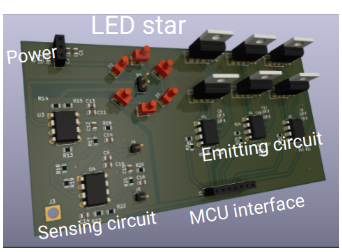

Fig. 4. Rendered PCB design from KiCAD

Multiple iterations of the PCB were attempted in this project, finally landing with the PCB design found in figure 4. As can be seen, the emitting and sensing circuits are separated physically, but they also feature different ground planes. Previous attempted PCBs were designed such that the two circuits shared the same ground plane, which introduced devastating noise to the sensing circuit.

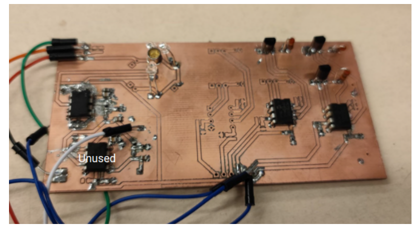

Fig. 5. Picture taken of the milled PCB

In the LED star, the LEDs are placed around the photodiode (imagined as the male pin-header in the middle), where the diodes are aiming towards the surface and positioned such that they don't shine straight into the photodiode.

The PCB we milled and constructed can be seen in figure 5. The reader might notice that some parts have not been soldered, and one of the opamps is noted as "unused". The unused opamp is due to previous designs including multiple cascaded non-inverting stages, which we did not use. The missing components are due to us only using three LEDs in the final design. More LEDs could have been soldered, but we decided against it due to lack of time and insufficient confidence that it would improve performance significantly.

III. Experiments and Data Collection

A. Experiment setup

Experiments with the circuit was first attempted by having the emitting and the receiving circuit on separate breadboards, like what is displayed in figure 6

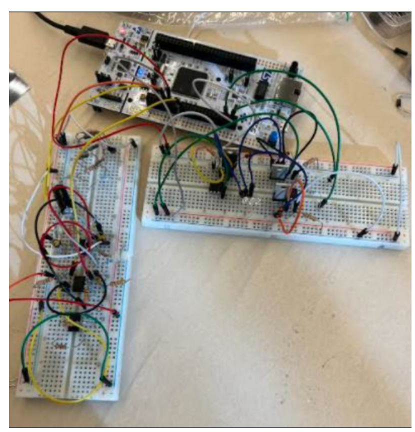

Fig. 6. Receiving(left) and emitting(right) circuits on breadboards

After we found the concept to be working, we moved on to milling the circuit on a PCB. This enabled us to then experiment with reflections of different surfaces. The surfaces used in the experiments were black plastic squares we printed in the 3D-printer, each filled with either water, ice or nothing.

The experiment was performed by setting up the PCB facing down towards the test surface from around 3cm as seen in figure 9, then pulsing the LEDs, and measuring the reflection from the surface. The data was collected and sent to a computer for further processing in python and matlab.

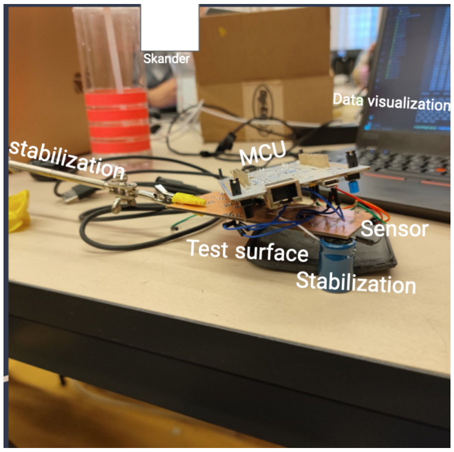

Fig. 7. Experiment setup

B. Data

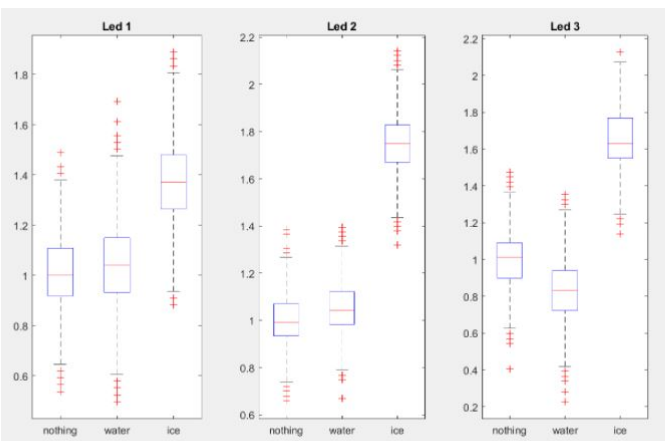

Fig. 8. Example of data for a measurement

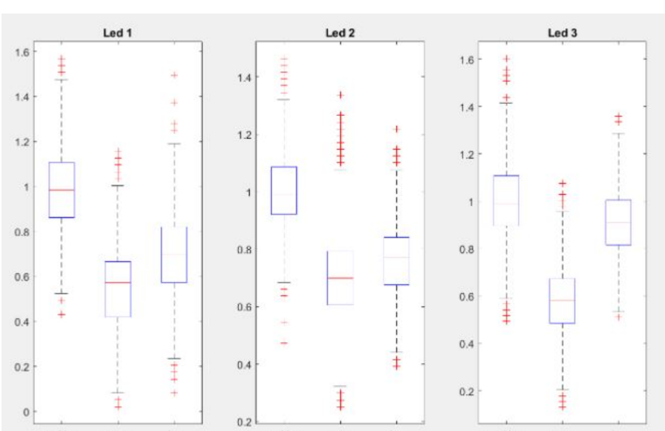

Fig. 9. Second example of measurement

We used Matlab to visualize the collected data after normalizing it with regard to the dry surface values. Some examples of plots we obtained can be seen in figures 8 and 9.

The data was very different across the measurements. We suspect the main cause of that to be the instability of the setup conditions, and the difficulty to have a reproducible ice surface. Also, the range from which we measured the reflections was relatively low, meaning that the little variations of distance to the surfaces would likely have more impact on the obtained values than the reflective properties of ice and water. Nevertheless, differences between the three types of surfaces can clearly be seen within each measurement. Unfortunately we were short on time to try to fit our data to some machine learning algorithm in order to build a model that would give the detected surface as an output. We also considered that it was necessary to collect better quality data that generalizes more if we wanted to have a decent performance in the model. This means we would need to improve the setup conditions and perhaps increase the range of the sensor beforehand.

IV. Member tasks

All the group members cooperated on testing the circuits on the breadboard. Skander and Robin worked on designing the PCB on KiCad as well as milling it in the mentorspace. Morgan worked on software design and assisted in designing and soldering the circuit. Samuel was responsible for reports and 3D-printing the surfaces, he also assisted with designing and milling the PCB.

V. Conclusion

The only satisfied requirement is that the sensor may consume less than 100 mW. The remaining requirements have not been met, as the project group did not attempt to characterize the sensor.

In addition to the above, each group member has written an independent conclusion that has been sent to Mark Smith by email.

References

[1] X. Ma and C. Ruan, “Method for black ice detection on roads using tri-wavelength backscattering measurements,” *Appl. Opt.*, vol. 59, no. 24, pp. 7242–7246, Aug 2020. [Online]. Available: http://opg.optica.org/ao/abstract.cfm?URI=ao-59-24-7242

[2] *Description of STM32F4 HAL and low-layer drivers*, 6th ed., STMicroelectronics, Chemin du Champ-des-Filles 39, Plan-les-Ouates, 1228, Geneva, Switzerland, Jul 2020. [Online]. Available: https://www.st.com/resource/en/user_manual/dm00105879-description-of-stm32f4-hal-and-ll-drivers-stmicroelectronics.pdf