UNIVERSITÀ DI PISA

DIPARTIMENTO DI INGEGNERIA CIVILE INDUSTRIALE

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Infrared Light Signaling Devices for Aerial Obstacles

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Introduction

1.1 The Slackline

Slacklining is the sport or discipline that involves balancing and maintaining equilibrium on a webbing stretched between two anchor points, which can be two trees, rocks in the mountains, or gym walls. The webbing used, the slackline, is usually made of nylon or polyester and has a width varying from 2.5 cm to 5 cm (one or two inches). The sport could be briefly described as tightrope walking performed on nylon/polyester webbings.

A particular variation of slackline is the **Highline**, that is, slacklining at height. It is usually set up between two mountain peaks, between two trees over a valley, or even between two buildings in a city.

1.2 Issues Related to Highlining

Webbings suspended in mid-air, such as Highlines, represent a significant risk to airspace if not properly managed and controlled. The presence of such infrastructures can interfere with the safety and navigation of helicopters operating nearby, as well as pose a threat to paragliders flying in the same area.

Over the years, the Highline community has adopted standard procedures regarding the signaling of lines, aware of all the existing issues. During daylight hours, multiple 2-meter-long windsocks are placed along a cord parallel to the line, providing effective visual signaling up to over a kilometer away. However, during nighttime, this technique is not as effective because it is not visible. At night, the only authorized aircraft is the rescue helicopter, which uses night vision devices for navigation that are very sensitive to infrared light. The use of signaling devices capable of emitting it represents an excellent solution.

1.2.1 Swiss Signaling Devices:

Few countries, like Switzerland, already include this type of installation in their local regulations. In the "Directive on Obstacles to Air Navigation," we find that, in addition to the mandatory notification to the local authority, it is necessary to equip the infrastructure with luminous signaling devices if the line is more than 100 meters above ground level. The official dossier can be consulted on the website of the "Federal Office of Civil Aviation (FOCA)."

The safety devices used by Swiss slackline communities are LED lights developed by a local company for an order of about 200 pieces. Although the product is marketed and certified, the price of 500 euros is prohibitive for many non-profit sports associations, and the expense for these devices is not justifiable in European countries where there is no legal obligation to use them. Moreover, the Swiss devices are equipped with an upper solar panel, which offers a significant advantage in terms of autonomy and versatility but sacrifices portability. In Switzerland, as in other countries, the installation of Highlines higher than 100 meters requires authorizations from local authorities and permits that cost hundreds of euros, so long-term installations are rare, making the photovoltaic cell unnecessary.

1.3 The Open Source Solution:

This thesis aims to fill the existing gap in the signaling of Highlines and temporary aerial installations. The main objective is to develop a complete product, accompanied by the publication of circuits and files for its realization, to establish the foundations for a reliable and affordable system. This system will be designed to be used in agreement with local helicopter units, to promote peaceful coexistence in airspace.

Product Development

2.1 Preliminary Studies

By drawing inspiration from the design of Swiss signaling devices, it was possible to design and develop a safety system based on already tested and reliable elements, while making improvements in the previously indicated areas. The process lasted about 4 years, during which 4 versions were created, progressively more elegant and technically advanced. Below are the last two complete and usable solutions.

2.2 Proof of Concept:

The prototype derives from a very careful and thorough study carried out in the summer of 2022 and can be defined as the first complete prototype tested in the field. It consists of a waterproof outer shell that encloses the electronic part inside, thus differentiating the container from the content. The upper shell is colored white and the lower one bright orange, ensuring visibility even during the day.

Through 4 practical hooks, it is possible to remove the upper shell and access the internal electronics, allowing both the deployment of the device and maintenance and control operations. Once operational, the signaling system provides infrared illumination by turning on the LED diodes at programmed intervals.

2.3 Proof of Work:

The fourth and final version of the device is more elegant and advanced both technically and mechanically. The knowledge acquired with the development of the previous prototype is consolidated with this device, making good use of potentially critical points. The result is a device with dimensions comparable to a smartphone, waterproof, and with efficient electronics that allow the device to operate for 4 days with a single battery.

The design of the device allows for its production and assembly on a large scale, without resorting to additive manufacturing technologies that are difficult to scale.

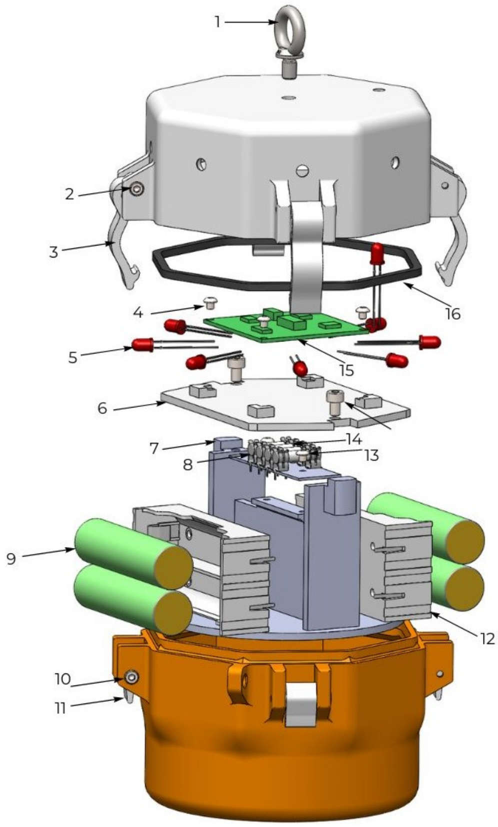

Figura 2.1: Proof of Concept

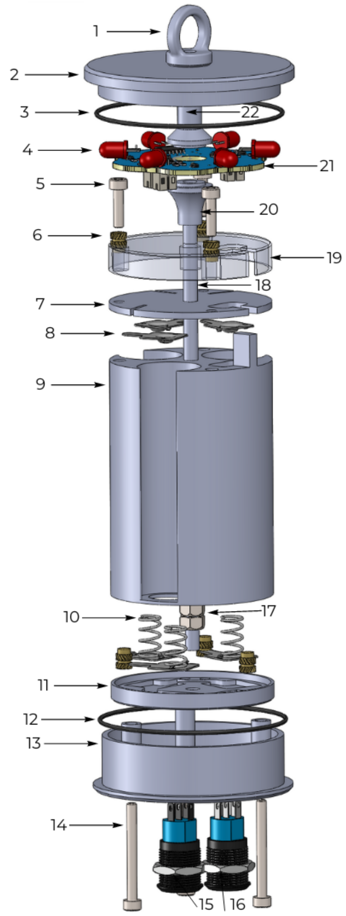

Figura 2.2: Proof of Work

2.3.1 Criticalities and Improvements of the Two Devices

Mechanical-Electronic Improvements:

Prototype 1	**Prototype 2**
Stresses in the closed configuration deform the outer shell. Phenomenon accentuated by the deviation of force lines along the outer shell.	The weight of the device is entirely supported by the threaded rod and then to the hook; the force lines are optimal.
Device resistant to splashes.	Device with underwater sealing
Overhanging LEDs are vulnerable and prone to easy breakage	Electronics completely protected inside the PMMA tube
Board made on protoboard, not dimensionally optimized	Printed circuit assembled using SMD technology. Dimensions drastically reduced.
LEDs powered with a non-specific power supply	LEDs powered with constant current using a LED driver.

User Experience Improvements:

Prototype 1	Prototype 2
Tedious battery charging process	Presence of USB-C port for charging
To operate the device, it is necessary to open the upper shell, disconnect connectors exposing the electronics.	The device is completely sealed and has only one external button for its control
It is not possible to check the battery charge status.	Upon startup, the device communicates the battery percentage by flashing an integrated LED from 1 to 5 times.

Tests and Results

Device	SWITZERLAND	PROTOTYPE 1	PROTOTYPE 2
Weight	1100 g	600 g	250 g
Dimensions	30 cm x 20 cm	16 cm x 15 cm	15 cm x 6 cm
Autonomy	Unlimited with sun	2 days per battery	4 days per battery
Charger	Solar cell/12 V	External 18650 charger	USB-C port
Cost	500 €	40 €	50 €
Customization	None	Ability to adapt each LED limited by power supply	Complete customization: selection of light pattern, type of IR LED, Batteries

Tabella 3.1: Comparison Table of Different IR Signaling Devices

3.1 Functionality Verification

For the functionality verification of the device, numerous tests were conducted to certify its robustness:

1. The waterproofness was verified both in the laboratory and with the deployment of the device in a rainy environment. Adhering to the ISO 20653 and DIN 60529 standards, it can be stated that the device has an IP67 protection rating;

2. Regarding autonomy, it was verified that using a single 18650 battery with a capacity of 3.2 Ah, the device lasts 40 hours in night configuration. Assuming a summer night duration of about 7 hours, an autonomy of 4 days per single battery can be estimated;

3. Operational validation was carried out in collaboration with the Trento helicopter rescue unit, which provided valuable advice for improving subsequent prototypes.

The device is highly visible even at a distance of 500 meters with the light pollution of the city near the airport, which is absent in mountain environments for which the device was designed.

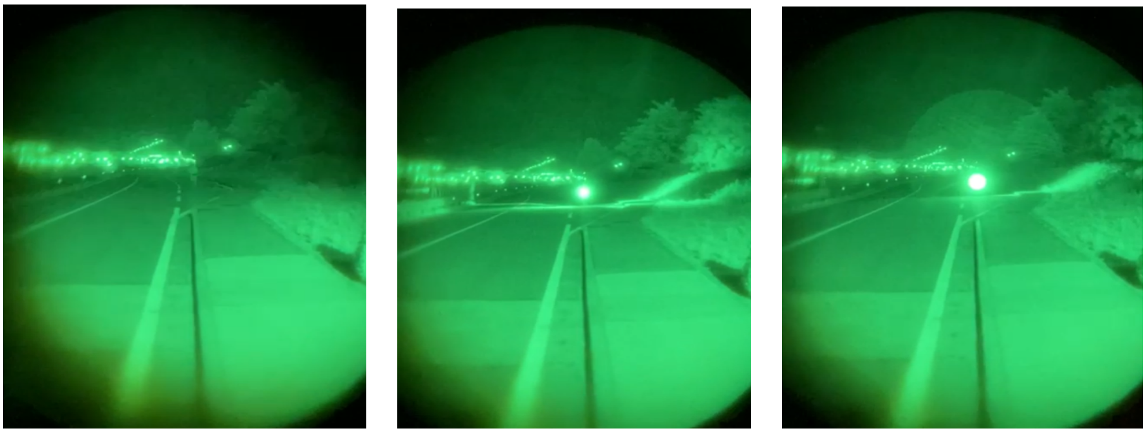

Figura 3.1: Photographs of the Device in Operation

Discussion and Conclusion

4.1 Future Implementations

Although the project is a complete and usable product, there are some points that could be expanded and perfected:

1. Although the device was built and designed with the possibility of adding an upper signaling LED, it was not implemented due to a lack of technological processes. For the LED to be visible from above, the upper cap must also be made of PMMA, achievable using a small CNC to engrave a plate;
2. The device features the IP2312 charging module soldered on top of the board. In future versions, to have a more elegant solution, it is possible to include both the 18650 charger and the respective BMS within the board.

4.2 Conclusions:

In conclusion, it can be stated that a device has been developed capable of successfully addressing the specific challenges, characterized by a lightweight, compact, and highly portable design. Additionally, its affordable and extremely convenient price makes it particularly suitable for non-profit communities interested in slacklining, where limited financial resources could hinder the adoption of safety devices equipped with infrared signaling.

Additional Resources and Images

5.1 Photographs

(a) Highline in the Sella Towers

(b) Swiss Devices

5.2 Proof of Concept:

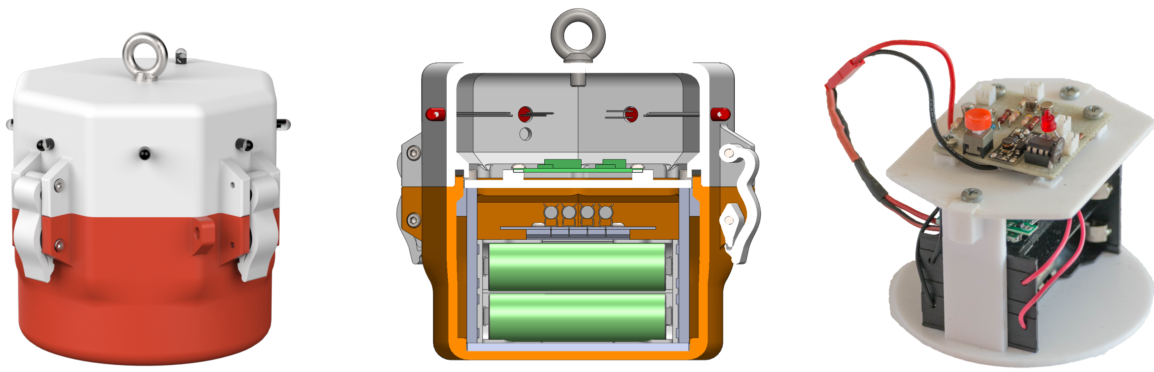

Figura 5.2: Renderings and Photographs

5.3 Proof of Work:

Figura 5.3: Renderings and Photographs

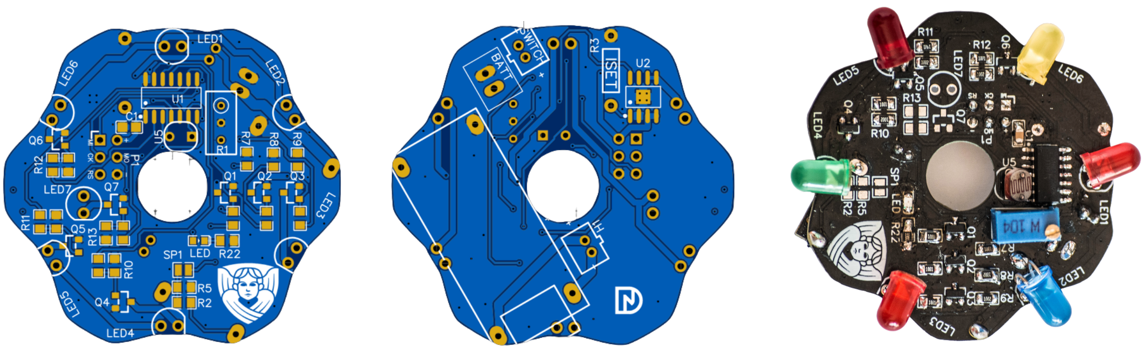

Figura 5.4: Renderings and Photographs