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Infrared Light Signaling Devices for Aerial Obstacles

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Introduction

1.1 Context

Slacklining is the sport or composite kinetic chain discipline that involves balancing and maintaining equilibrium on a dynamic 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).

Figura 1.1: Example of a boy practicing slacklining

Slacklining is an independent sport with multiple variants and disciplines, competitions, and professional athletes. It is also used as a support for balance training in competitive sports, as a fitness tool, and in physiotherapy.

Slackline (literally "slack line") is often compared to tightrope walking or tightrope (literally "tight cable") but differs in several aspects:

- The materials used: the former uses an elastic webbing made of synthetic fibers, while the latter uses a steel cable;
- The tensions applied to a slackline are much lower compared to those used by tightrope walkers;
- Lower tensions result in easier setup: anyone can install a slackline with the right instructions, whereas installing a tight cable requires more elaborate and complex equipment and materials;
- Slacklining is practiced bodyweight, without the use of a balancing pole as in tightrope walking.

1.2 Different Variations of Slacklining

1.2.1 Trickline

Tricklining is a discipline that combines slacklining and aerial acrobatics, using a 5 cm wide elastic webbing. Thanks to the high tensions applied, the webbing provides a trampoline effect, and trickliners perform jumps, bounces, rotations, flips, and grabs. Trickline is set up at about 150 cm in height for a length varying from 20 to 30 meters and includes world competitions with professional athletes sponsored by major manufacturing companies. Airline, a new form of tricklining promoted by Red Bull, involves installing multiple parallel tricklines at heights of 8-10 meters without using harnesses, but with a big airbag for protection.

1.2.2 Longline

The term "longline" refers to any slackline that exceeds 30 meters in length. For longlines, a 2.5 cm wide webbing is used, which can be installed at varying heights, lengths, and tensions (1-8kN). Tensioning the slackline requires an advanced tensioning system, such as a pulley winch, which necessitates a good understanding of the materials. The world record for longline belongs to Alex Schulz, who in May 2015 walked on a 610-meter-long slackline in the Mongolian desert.

1.2.3 Highline

Highline is slacklining taken to height, between two mountain peaks, between two trees over a valley, or even between two buildings in a city (urban Highline). Despite its extreme appearance, Highline has an excellent safety record; in fact, throughout its history, there has been only one fatal accident caused by incorrect use of materials and poor knowledge of them, still in the early days of the sport. Although the

Figura 1.2: Highline installed at the Sella Towers in 2020

media often describe Highliners as reckless thrill-seekers, this is not the case. On the contrary, Highline requires a very calm and relaxed approach, with a particular focus on self-control and managing one's emotions, especially fear. Additionally, Highlines are always installed by experts with redundancy in safety, meaning that each component of the entire system has a backup component that only activates in case of failure. The line itself has another line underneath it not under tension (called the 'backup') that serves only in case the mainline breaks.

Highliners almost always wear a climbing harness that connects them to the Highline via a leash (a piece of rope about 2 meters long) and a steel (or aluminum) ring that slides on the line, so that a fall results in only a short swing in mid-air. The World Record for Highline belongs to 3 of the 5 members of the French team SDD: Pablo Signoret, Nathan Paulin, and Lucas Millard. On June 9-10, 2017, they walked entirely on a 1662-meter-long Highline, placed 342 meters above the 'Cirque de Navacelles' valley in France. Lucas, the fastest in the crossing, took 1 hour and 6 minutes to accomplish the feat. Mr. Paulin, in a National Geographic interview after the Record, states: "When you're on a Highline, all your feelings are stronger: freedom, happiness, fear, love. Even the beauty of nature becomes more visible."

1.3 Historical Overview

Slacklining originated from a group of climbers in California in the late 1970s, in the national park emblematic of sport climbing and alpinism, Yosemite.

1.3.1 The First Slackline

In the early '80s, Adam Grosowsky arrived in Yosemite Valley to climb and came into contact with this form of equilibrism, which seemed to be exclusive to 'Camp 4'. During his studies at the University of Olympia, Washington, he had already experimented with equilibrism on steel cables and climbing ropes with his friend Jeff Ellington. Then, the two pioneers were the first to install a piece of 2.5 cm wide tubular nylon webbing, commonly used in climbing: thus, Slacklining as we know it today was born—the pursuit of balance on a flat and dynamic webbing. To tension the webbing, Jeff Ellington developed a special technique, the "Ellington" (later also called "primitive"), a self-locking tensioning system made with the same webbing on which one walks and a pair of carabiners. Due to its simplicity, efficiency, and low material cost, this system is still the most widely used for 2.5 cm slacklines. The origin of the term "Slackline" does not refer to a particular person or date in history; however, it logically seems to derive from "Slackchain" and "Slackwire" (both terms Grosowsky and Ellington used to define their form of equilibrism): "Slack" indicating the sag (the height difference between the anchor points and the center of the loaded webbing) remained, while the medium on which the sport is practiced changed into something entirely new, the webbing called "line."

1.3.2 The First Highline

In 1981, Scott Balcom and Chris Carpenter were inspired by Grosowsky and Ellington, who attempted to tension and walk a steel cable between The Lost Arrow Spire (a highly exposed rock tower) and the main wall of the Yosemite massif. The two friends then began training not for a tightrope performance at height but for a true Highline consisting of three layers of webbing. For this reason, in 1983, together with Ric Phiegh, Rob Slater, and Chuck “Chongo” Tucker, they installed the first documented Highline in history under a highway bridge near Rose Bowl in California, which they called "The Arches." Only after many attempts did Scott Balcom become the first man to walk the Lost Arrow Spire Line on July 13, 1985, secured to the line with a safety device called the Highline Leash. In 1993, Darrin Carter was

Figura 1.3: One of the first slacklines in the Yosemite Valley

the second to walk the Spire Line, and in 1995 he repeated the feat unbelted, without safety devices. In 2007, Libby Sauter was the first woman to walk the historic line of The Lost Arrow Spire, followed shortly after by Jenna McLennan.

Figura 1.4: First Highline installed at "The Lost Arrow" Spire

1.4 Highline Installation

Spectacular lines immersed in breathtaking landscapes often leave many doubts about how the webbing is passed and where it is anchored. Being a potentially dangerous and fatal sport, standard procedures have been developed and refined over the years to ensure the safe installation of the line. For this reason, each component of the installation is oversized and redundant to eliminate any risks due to potential errors and manufacturing inaccuracies. Specifically, the installation steps for a Highline are listed below.

1. **Location Selection for Installation:**
   This step is one of the most critical because, as highlighted later, the danger of the installation to air traffic mainly depends on its location. Once the possibility of installation is confirmed, sometimes by requesting permission from the competent authorities, the anchoring itself can proceed.

2. **Construction of Anchors:**
   For Highline anchoring, an anchor setup refers to the combination of devices such as ropes, nails, and carabiners necessary to connect and anchor one end of the suspended rope.

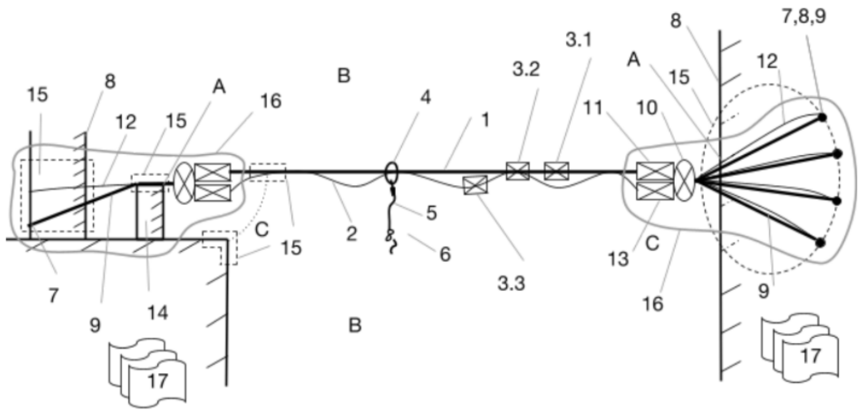


Figura 1.5: Schematic representation of an anchor setup

There are mainly 2 types of anchors that can be used: natural anchors and rock anchors. Natural anchors involve ropes or truck straps wrapped around multiple trees and shrubs with a significant diameter. Rock anchors, on the other hand, consist of ropes or truck straps connected to expansion bolts in the rock. Expansion bolts are the same ones used and certified for climbing, where despite their small diameter of 10-12mm, they guarantee a resistance of 25kN when subjected to tension. These are inserted after drilling a hole in the rock with a percussion drill and fixed irreversibly by tightening the upper nut with a wrench. It is important to note, however, that rarely is the critical point of an installation the bolt itself, as its hold mainly depends on the compactness and

solidity of the rock, which is usually the weakest link in the chain. Additionally, the anchor setup is usually configured to distribute the line's load evenly across multiple bolts, maintaining an operational safety coefficient well above 5.
For aesthetic and safety reasons, it is important that both anchors are at the same height to avoid the line sloping downward or upward. Otherwise, the subsequent walk would be much more strenuous and less enjoyable.

3. **Passing the Webbing from One Anchor to Another:**
   Once the anchor setup is complete, the slackline is passed from one anchor to the other. It is possible to manually transport all the material only on rare occasions, such as in hill passes where the absence of friction and sharp obstacles allows first placing the line on the grass and then tensioning it at a later time.
   In most cases, however, it is necessary to use a drone, such as a DJI MavicPro or similar, to pass a very thin and lightweight cord between the two anchors. Typically, tuna fishing leader wire is used, capable of holding up to 50kg of weight while weighing less than 1kg. To prevent the wire from getting caught in the drone's propellers due to turbulence, it is tied to a carabiner attached to the quadcopter.

   In most cases, the slackline's weight is too high to be passed directly, requiring intermediate steps by replacing ropes with progressively thicker diameters. Usually, after the tuna fishing leader wire, a nylon or dyneema cord commonly called a "Tagline" is passed. It is a rope about 5mm in diameter, capable of holding about 220kg.
   If a drone cannot be used, either due to unavailability or because of no-fly zone restrictions, it is possible to skip passing the fishing leader wire and proceed only with passing the tagline. Both teams throw a stone from their respective anchors, and a person connects the two ends with a knot.
   In conclusion, whether using the drone approach or not, the Tagline is tensioned and replaced by passing the slackline. The drone approach is preferred as it is often very difficult to free the cable from branches and obstacles during tensioning.

4. **Finalizing the Installation:**
   Once the slackline and necessary materials are passed, the installation's security is ensured by checking that all devices are correctly configured and then tensioning the line.

Installation of Long Slacklines:

Long slacklines of 300m can reach a total weight of 20kg, entirely loaded onto the cord, making it difficult to handle with ease. The high load also causes the cable to sag about ten meters in height, increasing the possibility of getting caught on trees and rocks during installation.

To date, there is also another method for passing the line called the "drying rack method" or "Buon Chacho."
Unlike the traditional method, the latter involves tensioning the tagline, bringing it to a tension of a couple of kN, and then passing the entire slackline through special pulleys that run on the tightened cable. In Italian, this method is also called the "Drying Rack Method" due to its mechanical similarity to a shower curtain rod, where the weight is distributed along a wire/pole using rings.

1.5 Issues Related to Highlining

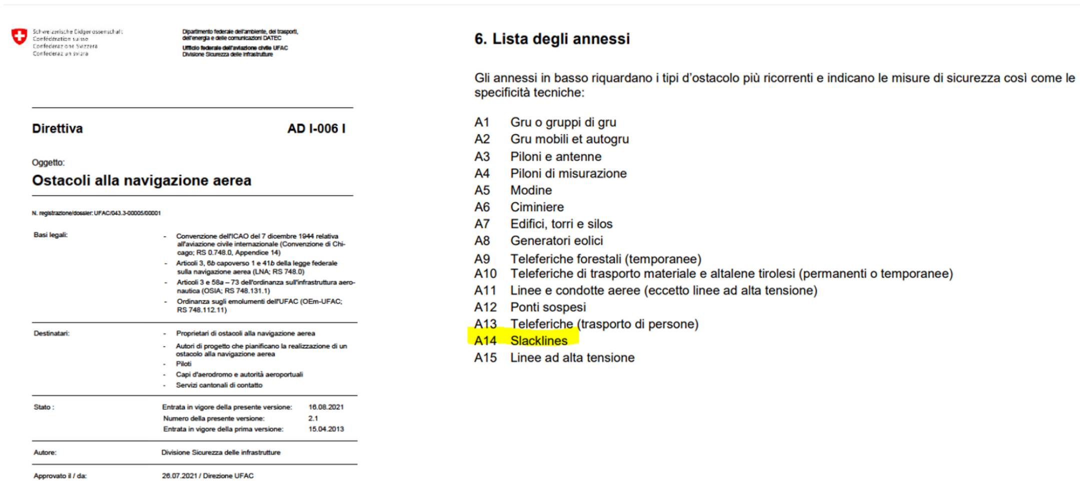
Webbings suspended in mid-air, such as Highlines, represent a significant risk to airspace if not properly managed and controlled. The presence of such infrastructures can interfere with the safety and navigation of helicopters operating nearby, as well as pose a threat to paragliders flying in the same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

The most spectacular Highlines, i.e., those installed in mountainous territories, are usually located near famous climbing routes, cliffs, and via ferratas. This is due to both practical factors, as the two anchors must be set up on both sides before passing the line, and aesthetic reasons, as famous and classic climbing routes are typically found in panoramic spots. However, this proximity poses an additional problem for the Helicopter Rescue Unit, as the most frequent assistance cases occur on the most well-known, equipped routes mentioned earlier.

Over the years, the Highline community has adopted standard procedures regarding the signaling of lines, aware of all the aforementioned issues. Some countries, as will be illustrated in the next paragraph, already include this type of installation in their local regulations.

1.5.1 The Swiss Solution

Few countries, like Switzerland, have already regulated and legislated the installation methods, making slacklining a complete sport with legalized associations and festivals.



Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Dipartimento federale dell'ambiente, dei trasporti, dell'energia e delle comunicazioni DATEC
Ufficio federale dell'aviazione civile UFAC
Divisione Sicurezza delle infrastrutture

Direttiva **AD I-006 I**

Oggetto:
Ostacoli alla navigazione aerea

N. registrazione/dossier: UFAC/043.3-00005/00001

Basi legali:	- Convenzione dell'ICAO del 7 dicembre 1944 relativa all'aviazione civile internazionale (Convenzione di Chicago; RS 0.748.0, Appendice 14) - Articoli 3, 6*b* capoverso 1 e 41*b* della legge federale sulla navigazione aerea (LNA; RS 748.0) - Articoli 3 e 58*a* – 73 dell'ordinanza sull'infrastruttura aeronautica (OSIA; RS 748.131.1) - Ordinanza sugli emolumenti dell'UFAC (OEm-UFAC; RS 748.112.11)
Destinatari:	- Proprietari di ostacoli alla navigazione aerea - Autori di progetto che pianificano la realizzazione di un ostacolo alla navigazione aerea - Piloti - Capi d'aerodromo e autorità aeroportuali - Servizi cantonali di contatto
Stato :	Entrata in vigore della presente versione: 16.08.2021 Numero della presente versione: 2.1 Entrata in vigore della prima versione: 15.04.2013
Autore:	Divisione Sicurezza delle infrastrutture
Approvato il / da:	26.07.2021 / Direzione UFAC

6. Lista degli annessi

Gli annessi in basso riquardano i tipi d'ostacolo più ricorrenti e indicano le misure di sicurezza così come le specificità tecniche:

A1 Gru o gruppi di gru
A2 Gru mobili et autogru
A3 Piloni e antenne
A4 Piloni di misurazione
A5 Modine
A6 Ciminiere
A7 Edifici, torri e silos
A8 Generatori eolici
A9 Teleferiche forestali (temporanee)
A10 Teleferiche di trasporto materiale e altalene tirolesi (permanenti o temporanee)
A11 Linee e condotte aeree (eccetto linee ad alta tensione)
A12 Ponti sospesi
A13 Teleferiche (trasporto di persone)
A14 Slacklines
A15 Linee ad alta tensione

Figura 1.6: Types of obstacles listed in Swiss regulations

The official dossier can be consulted on the "Federal Office of Civil Aviation (FOCA)" website. Within the document, all types of obstacle signaling that pose a threat to air navigation are listed.

Specifically, in paragraph A14 "Slacklines" Figura 1.6, all necessary requirements for correct signaling are provided, differentiating slacklines placed in developed and undeveloped areas, at different heights. As stated in the document, in addition to 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.

Below are some important points:

- It is always mandatory to register all lines over 25 meters with the local authority BAZL;
- Above a height of 40 meters, orange balls must be placed at the anchor points;
- Above 60 meters, an official permit is required, which usually incurs a cost;
- Above 100 meters, a parallel rope with windsocks or orange balls must be installed every 50-100 meters. Additionally, infrared lamps must be positioned for nighttime safety;
- Low-intensity signaling must be positioned at the ends of the strap at a minimum height of 2.5m above the ground and at regular intervals on a separate marking rope.

The Swiss standard has thus become an excellent example for all Slackline communities, a reference point for developing their local solutions.

Illustrazione 57

Illustrazione 58

Figura 1.7: Examples of signaling devices required for Highlines

1.5.2 Swiss Signaling Devices

The signaling devices used by Swiss slackline communities are LED lights developed by a local company for an order of about 200 pieces. The devices consist of a printed circuit board made with Through-Hole (TH) technology containing all necessary components, enclosed in a durable and waterproof outer casing. The LED signalers are not user-openable, and the batteries can be recharged through the dedicated connector located at the bottom or by using the photovoltaic panel.

Advantages and Disadvantages of the Device

The upper solar panel represents a significant advantage in terms of device autonomy and versatility. For installations intended to remain mounted for weeks or even months, any other solution would be risky. On the other hand, using this technology does not allow for the creation of portable and compact devices, as the solar cell requires a considerable surface area to function. In Switzerland, as in other countries, installing Highlines over 100 meters requires authorization from local authorities and permits that cost hundreds of euros. Therefore, long-term installations are rare, and Highlines are often more alpine in nature, remaining mounted for only a few nights. The price of 500 euros is prohibitive for many non-profit sports associations, and the surplus imposed by the company is very high when analyzing the materials used. Using these devices is not applicable in European countries where there is no legal obligation to use them.

Figura 1.8: Swiss Signaling Device

1.6 The Open Source Solution

This thesis aims to fill the existing gap in the signaling of aerial slacklines. The main objective is to develop a complete product, accompanied by the publication of circuits and files for its realization, to lay 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.

The project aims to be a reference point for the various associations facing similar issues, with the intention of making all materials, steps, and related history public. This will provide a solid starting point for future signaling lights, offering an opportunity for development and standardization in the sector.

Furthermore, the product's field validation through the use of appropriate visors by the helicopter rescue unit represents an additional guarantee of its effectiveness and functionality. This contributes to providing greater confidence in the adoption and use of the system, enhancing the safety and reliability of aerial slacklines in managing airspace.

Capitolo 2

Product Development

2.1 Preliminary Studies

Over the past 5 years, numerous prototypes have been developed aimed at filling this gap in the sport. The path followed can be summarized in five distinctive stages, during which as many products were created at different times, characterized by a progressive refinement and an ever-increasing technical and conceptual sophistication.

2.1.1 The first attempt

The request to create a first infrared signaling device came to me and my colleagues in the summer of 2018, during the planning for an important slackline event in Madonna di Campiglio. The line was set up in the Adamello Brenta Natural Park, for the documentary on Italian slacklining titled "Voglio che stai bene". The line was 200 meters high and about 550 meters long. When requesting permits, the local helicopter rescue unit specifically requested the use of an infrared signaling device, given the significant exposure to air traffic and the dangerous position in case of rescue operations in nearby areas.

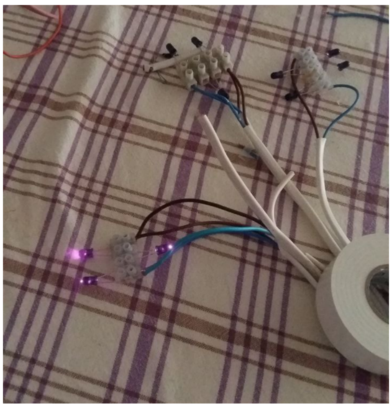


Figura 2.1: First rudimentary prototype

The system was very rudimentary and consisted of a copper cable coated with a length of about 500 meters, where every 100 meters, 3/4 infrared LEDs were placed. At that time, my knowledge of electronics was very basic, compared to the current one.

The final product presented several critical issues such as:

- The system was powered by a 12V motorcycle battery, which made it bulky and heavy;
- Using such long cables posed a problem due to their characteristic resistance, dissipating much of the useful energy;
- The infrared diodes were not suitable for that application, their wavelength was not optimal, and the lack of an on/off pattern made the LEDs not noticeable from a distance;
- The system was neither waterproof nor splash-resistant.

2.1.2 The second attempt

In the second attempt, the focus was on exploring the portability of the system, trying to move from a device powered by a battery located remotely and connected via a cable, to a more portable modular solution. Although it was a step forward in terms of user experience and reduced size, all other issues of the previous prototype persisted, forcing us to explore different paths in subsequent projects.

Figura 2.2: Second rudimentary prototype

2.2 Proof of Concept:

2.2.1 Introduction

The first complete and usable construction solution

The prototype originates from a much more thorough and detailed study conducted in the summer of 2022 and can be defined as the first complete prototype tested in the field.

Unlike previous devices, this one consists of a waterproof exterior shell that houses the electronics inside, separating the container from the content. The upper cover, as seen in the render in Figura 2.3, is colored white on top and bright orange on the bottom. This configuration provides the device with dual functionality, as it allows it to signal the presence of an aerial obstacle even during the day, serving a similar function to traditional windsocks.

Figura 2.3: Render of the device

Using 4 practical hooks, the white upper cover can be removed to access the internal electronics, allowing the device to be set up and maintained. Once operational, the signaling system provides infrared illumination by switching the LED diodes on and off at programmed intervals.

Below are the CAD drawings of the components of the subsequently produced devices. For clarity, nuts/washers/o-rings for the upper hook and the silicone used to permanently seal the LEDs have been omitted.

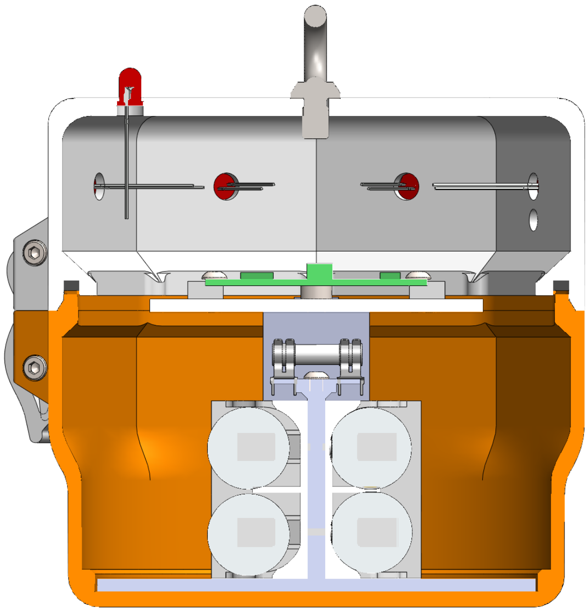


Figura 2.4: Section view of the device

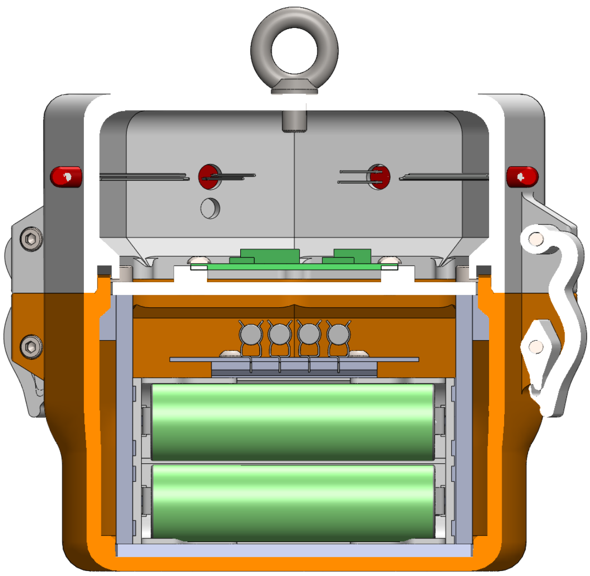


Figura 2.5: Section view of the device

2.2.2 Components

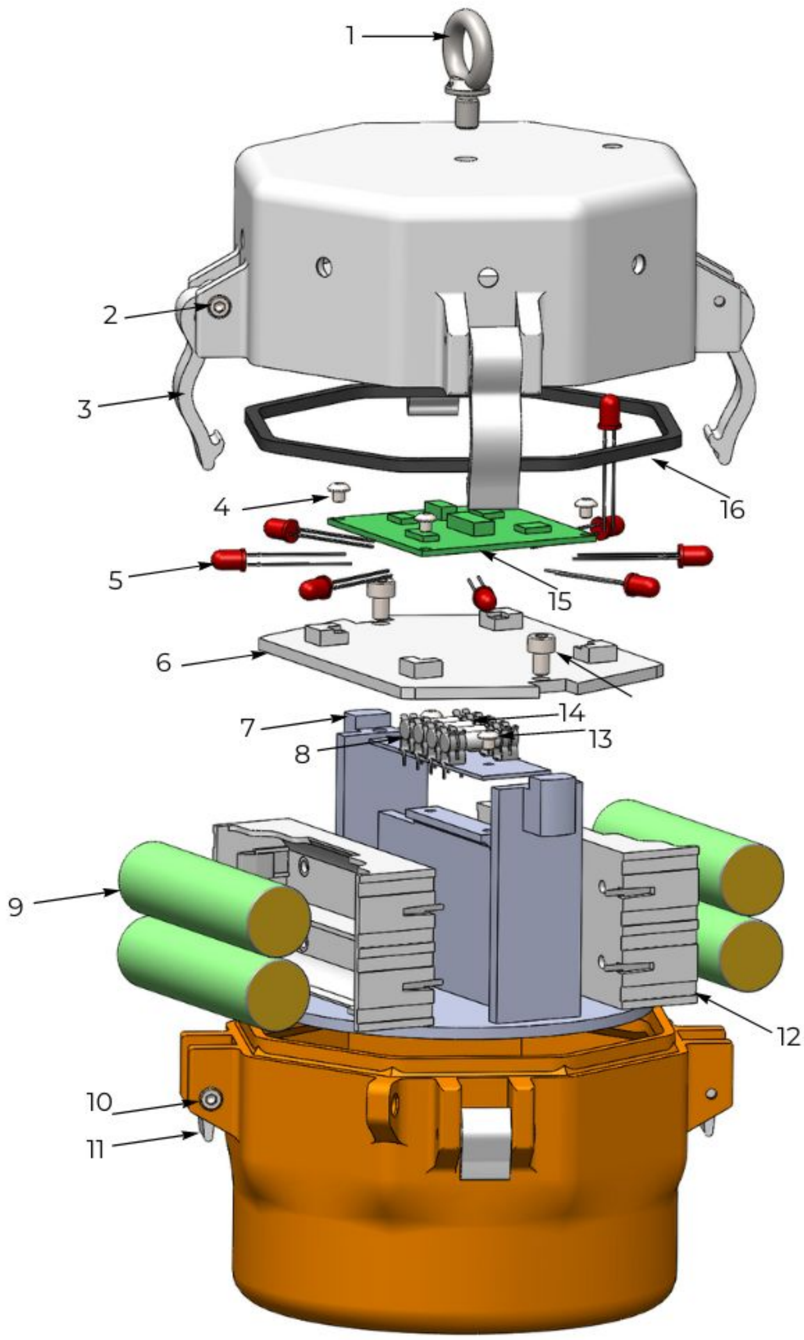


Figura 2.6: Exploded view

Bill of Materials

Numbers	**Element**	**N.Components**	**Material**
1	M4 Eyelet and nut	1	Stainless Steel
2	M3x20 Screw	4	Stainless Steel
3	Closing hook	4	PETG
4	M3x6 Screw	4	Stainless Steel
5	Infrared LEDs	9	N.C.
6	PCB Holder	1	PETG
7	Lower Structure	1	PETG
8	BMS and fuse holder	4	N.C.
9	18650 Battery	4	N.C.
10	M3x20 Screws	4	Stainless Steel
11	Closing cam	4	PETG
12	18650 Holder	2	PE
13	M3x10 Screws	2	Stainless Steel
14	3A Fuses	4	N.C.
15	PCB	1	N.C.
16	Gasket	1	TPU
17	Lower Cover	1	PETG
18	Upper Cover	1	PETG

Tabella 2.1: Bill of materials

Material	**PLA**	**PETG**	**ABS**	**ASA**
Glass transition temperature	65°	75°	105°	106°
Waterproof	Yes	Yes	No	Yes
UV resistance	No	Yes	No	Yes

Tabella 2.2: Comparison of common materials for outdoor use

Capitolo 3

Tests and Results

3.1 Functionality Verification

In terms of functionality verification, numerous tests were conducted to certify the robustness of the device. Laboratory tests were performed following the standards used in the commercial sector, such as IP68, IP67, and procedures for certifications related to water and dust resistance. The following sections will illustrate the results and methodologies used.

The operational validation of the device was carried out in collaboration with the helicopter rescue unit of Trento. I would like to extend my sincere thanks for their valuable contribution during this phase and for the helpful advice provided for the improvement of subsequent prototypes.

3.2 Laboratory Functionality Tests

Battery Duration

To verify the battery life of the device, both theoretical calculations and practical tests were carried out. As mentioned in previous sections, different usage phases of the device correspond to different consumption levels.

It is important to note that the consumption depends on the electronics used, while the duration is strictly related to the routine selected during the device's programming. Table Tabella 3.1 shows the measurements corresponding to the specific device created for the testing phase. The timings refer to a complete cycle of the IR LED being turned on and repeated under low light conditions. During the day, when the use of the IR LEDs is not necessary, the device's consumption is negligible and can be disregarded.

Using a single 18650 battery with a capacity of 3.2 Ah, it is possible to calculate the device's autonomy of 40 hours in night mode using the formula 3.2. Assuming a summer night lasts about 7 hours, the estimated duration is 4 days per battery.

Device Usage Phase	Current Consumption	Duration
Red Integrated LED On	10 mA	400 ms
IR LED On	200 mA	1.5 s
Standby	3 uA	2 s

Tabella 3.1: Consumption and duration of the various phases of the device

$$DurataBatteria = \frac{CapacitaBatteria}{\sum Durata * ConsumoCorrente} \tag{3.2}$$

During laboratory testing, a battery life of approximately 35 hours was confirmed for a single battery. The deviation from the theoretical value is due to approximations in the preliminary calculations, including not accounting for consumption during the transition between different phases.

Waterproofing

To verify the waterproofing of the device, tests were conducted both in the laboratory and through the device's use in rainy conditions.

In the field of electronic engineering and device design, the concept of "IP waterproofing" is defined by the ISO 20653 and DIN 60529 standards. The acronym "IP" stands for "Ingress Protection" and represents a globally recognized standard to evaluate the level of protection offered by a device or enclosure against the ingress of external elements, whether solid like dust and debris or liquid like water and moisture. The IP rating is expressed by two digits, defined in the standard.

ISO 20653	DIN EN 60529	Significato: Protezione contro corpi estranei, polvere e contatto
0	0	Nessuna protezione
1	1	Protetto contro corpi estranei solidi con diametro ≥ 50 mm e contro l'accesso con il dorso della mano
2	2	Protetto contro corpi estranei solidi con diametro ≥ 12,5 mm e contro l'accesso con un dito
3	3	Protetto contro corpi estranei solidi con diametro ≥ 2,5 mm e contro l'accesso con un utensile
4	4	Protetto contro corpi estranei solidi con diametro ≥ 1,0 mm e contro l'accesso con un filo metallico
5K	5	Protetto contro la polvere in quantità nocive e completamente protetto contro il contatto
6K	6	A tenuta di polvere e completamente protetto contro il contatto

Figura 3.1: Table showing the meaning of the first digit in IP rating

After conducting the tests in the laboratory, it was concluded that the device is completely waterproof and submersible. Since it was not tested for long periods of immersion, we can assert that the device has an IP67 protection rating.

ISO 20653	DIN EN 60529	Significato: Protezione contro l'acqua
0	0	Nessuna protezione
1	1	Protezione contro lo sgocciolamento dell'acqua
2	2	Protezione contro la caduta di acqua gocciolante quando la custodia è inclinata fino al 15°
3	3	Protezione contro la caduta di acqua nebulizzata fino a 60° dalla verticale
4	4	Protezione contro gli spruzzi d'acqua da tutti i lati
4K		Protezione contro gli spruzzi d'acqua con aumento della pressione su tutti i lati
5	5	Protezione contro i getti d'acqua (ugello) da qualsiasi angolazione
6	6	Protezione contro i forti getti d'acqua
6K		Protezione contro i forti getti d'acqua ad alta pressione, specifica per i veicoli stradali
7	7	Protezione contro l'immersione temporanea
8	8	Protezione contro l'immersione permanente
	9	Protezione contro l'acqua durante la pulizia ad alta pressione/getto di vapore, specialmente in agricoltura
9K		Protezione contro l'acqua durante la pulizia ad alta pressione/getto di vapore, specialmente per i veicoli stradali

Figura 3.2: Table showing the meaning of the second digit in IP rating

3.3 Field Testing

As mentioned in the introduction, thanks to close collaboration with the Helicopter Rescue Unit in Trento, the proper functioning of the device was verified. The testing process involved multiple meetings during which critiques and suggestions were raised to improve the product.

The initial phase of the device's testing was carried out in 2022, followed by the testing of the second device in the summer of 2023. The trials were initially conducted at the landing strip of Caproni Airport and later moved to a local road due to excessive lighting at the strip.

Results

The photos in Figura 3.3 show the implementation of the device. They were taken with a phone and using the night vision goggles provided by the local helicopter rescue unit. The device was significantly visible even from a distance of 500 m, despite the light pollution from the nearby city and airport, which was not present in the mountainous environments for which the device was designed.

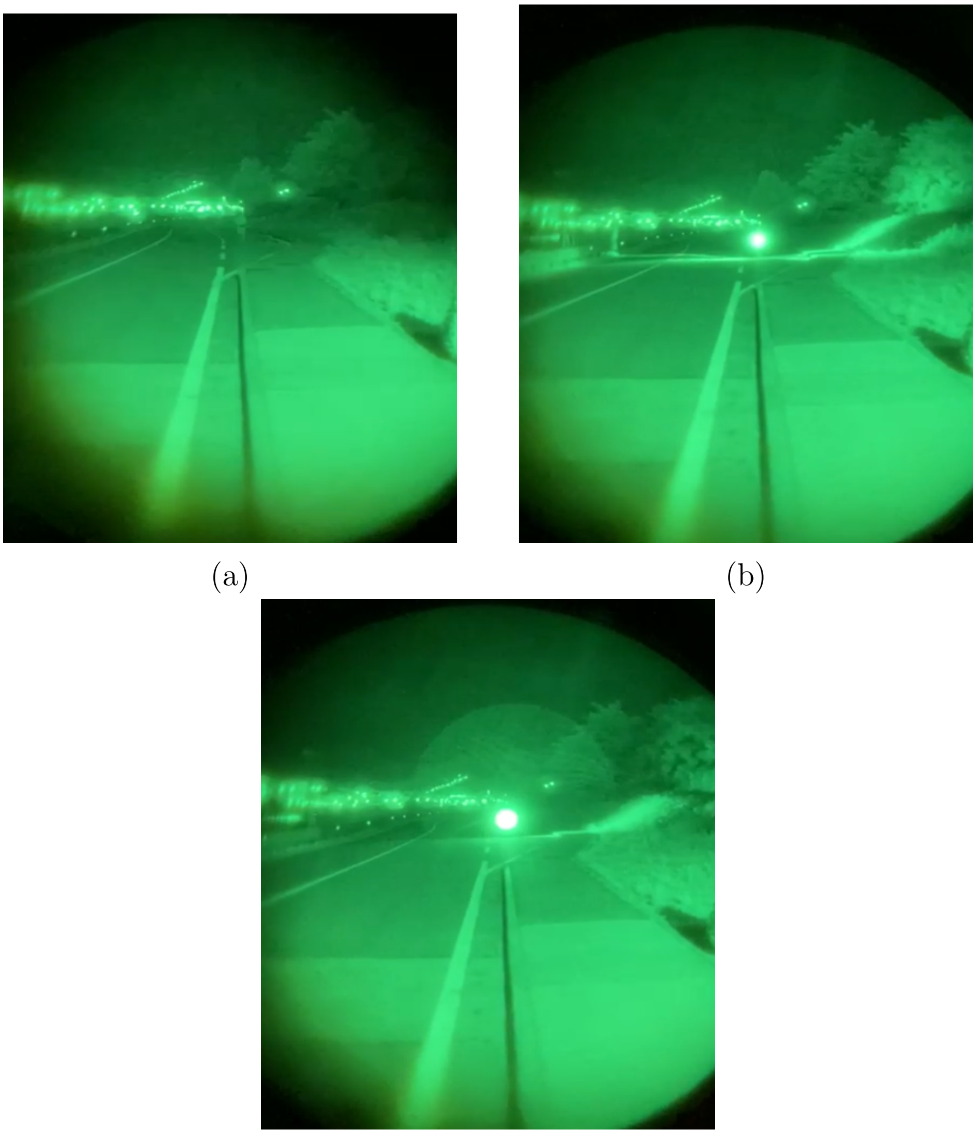

(a) (b) (c)

Figura 3.3: Photos of the device in operation

3.4 Product Comparison

Summarizing some of the features of the devices outlined in this document, we can create the comparison table Tabella 3.2. From the analysis of the table, it is clear that the product has continuously improved over time, leading to the current version.

Device	SWISS	PROTOTYPE 1	PROTOTYPE 2
Weight	1100 g	600 g	250 g
Dimensions	30 cm x 20cm	16 cm x 15 cm	15 cm x 6 cm
Autonomy	Unlimited with solar	2 days per battery	4 days per battery
Charger	Solar panel / 12V	External 18650 charger	USB-C port
Cost	500 €	40 €	50 €
Customization	None	Ability to adjust each light diode within power limits	Full customization: choose light pattern, IR LED type, Batteries

Tabella 3.2: Comparison table between different IR signaling devices

Capitolo 4

Discussion and Conclusion

4.1 Future Implementations

Although the project represents a complete and finalized product, there are still a few aspects that could be expanded and improved, as listed below:

1. Despite the device being designed and built with the possibility of adding an upper signaling LED, it was not implemented due to technological limitations. To ensure that the light diode is visible from above, the top cap must be made of PMMA. This can be easily manufactured with a small CNC machine to carve a sheet.

2. The device includes the IP2312 charging module soldered onto the board. In future versions, to achieve a more elegant solution, both the charger for the 18650 batteries and the corresponding BMS could be integrated directly into the board. In particular, the lower space appears to be sufficiently large to allow for their implementation.

4.2 Conclusions

This project represents the culmination of a long individual journey, during which I had the opportunity to develop a wide range of skills in different fields. Through the evolution of this project, I acquired and consolidated essential knowledge, such as 3D design and fabrication via 3D printing, the creation of advanced electronic circuits, and the programming of embedded systems.

I hope that with this project, I have contributed to the slackline community in the area of aerial safety and signaling, with the hope that others will continue to contribute to the GIT of this project in the future. In conclusion, it can be confidently stated that a device has been developed that effectively addresses the specific challenges, characterized by a lightweight, compact, and highly portable design. Furthermore, its affordable and highly cost-effective nature makes it particularly suitable for non-profit organizations involved in slacklining, where limited financial resources might hinder the adoption of infrared signaling devices.

Bibliografia

[1] Maria Pia Pedeferri Barbara Del Curto, Claudia Marano. *Materiali per il design. Introduzione ai materiali e alle loro proprietà*. 2015.

[2] Basso. *Dispense elementi di Elettronica*. Unipi.

[3] Sirio Izzo. L'arte della slackline.

[4] Marco Raugi. *Lezioni di elettrotecnica*. Pisa University Press, 2013.

[5] Kurt M. Marshek Robert C. Juvinall. *Fundamentals of Machine Component Design, 7th Edition*. 2019.

[6] Paul Scherz. *Practical Electronics for Inventors*. Wiley, 2006.